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Reports
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Supplement to: Development of User Guidelines for Selected Retardant Aircraft

SUPPLEMENT TO:

DEVELOPMENT OF USER GUIDELINES FOR SELECTED RETARDANT AIRCRAFT

Final Report

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Contract 26-3332

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U.S. Department of Agriculture
Forest Service
Intermountain Forest and Range Experiment Station
Ogden, Utah, 84401

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Dear

Enclosed for your reference is a document which is a "Supplement to Development of User Guidelines for Selected Retardant Aircraft." The document covers additional analysis and studies conducted in preparing air tanker performance guidelines, and model changes related to the "Air Tanker Performance Guides" you have already received. (This is not to be confused with the original report, "Development of User Guidelines for Selected Retardant Aircraft" by D. H. Swanson et al, February 1975.) The background and content of the report is pretty well covered in pages 1-5 of the report.

This report provided the basis for the development of guidelines previously distributed, covering 12 different tank and gating systems and approximately 60 or 70 actual air tankers (as shown by the list of applicable aircraft given in the technical data sections of the performance guides). A number of additional aircraft guides are presently being prepared which include the Aero-Union tanked DC-4 and C-130 MAFFS. As static test data and funds are available, other aircraft may be included.

We also now have a supply of the "Air Tanker Performance Guides" which are available. If you wish to arrange for copies of the guide, please give me a call or drop me a line.

Sincerely,

CHARLES W. GEORGE
Project Leader

Enclosure

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SECTION I
INTRODUCTION

This report documents extended work on Contract 26-3332 for the Development of User Guidelines for Airtanker Mission Planning. The work was authorized under Change Orders 1 through 3 and amendment 2 to the subject contract. The report supplements information contained in the Honeywell final report, "Development of User Guidelines for Selected Retardant Aircraft" (Ref. 1), and in individual Airtanker Performance Guides published under separate cover.

The extended effort resulted in:

- Generation of additional Airtanker Performance Guides covering:
    1. Aero Union DC-6 (2400-gallon load)
    2. Aero Union DC-6 (3000-gallon load)
    3. Aero Union C-119
    4. Hawkins and Power C-119
    5. Rosenbaum DC-6
    6. Stell PB4Y2
    7. Aero Union S2F
    8. Intermountain B-17
- Guide format revisions including: (a) technical data sheets documenting specific test data on which the guideline material is based and (b) a consistent set of ground safety criteria based on Forest Service data relating forward velocity of the pattern to flow-rate parameters.

- Modifications to the computer programs to improve predictions and facilitate guideline generation.

This report describes and discusses program-change efforts in three areas:

- Correction of Simulation Rules Differentiating Between Retardant Types (Section III)
- Development of a Subroutine to Predict Flow Rate from Tank Parameters (Section IV)
- Development of Rules of Thumb for Estimating Performance of Downloaded Tanks (Section V)

SECTION II
SUMMARY

Work on the High Altitude Drop Mechanization Study (Ref. 2, 3) resulted in the development of a computer simulation capable of predicting retardant ground patterns over a range of aircraft velocities and altitudes. Employing this simulation, it is possible to run any aircraft for which measured flow-data are available through an extensive computer-generated test series, such as that conducted on the CL-215 by the Forest Service. Since each flight takes less than 1 second of computer time, a thorough examination of tanking capabilities can be conducted in a few days, allowing for preparation of input, validation of the runs, and repeats as necessary.

The objective of Contract 26-3332 (User Guidelines) was to develop procedures to digest and summarize the potentially vast amount of data thus generated in terms and format useful to operational personnel. The effort also included improvements in the simulation model, its documentation, and initial publication of Guidelines on the CL-215, Aero Union B-17, Gilbertson DC-6B, and Hemet Valley S2F aircraft. This work is described in the final report, "Development of User Guidelines for Selected Retardant Aircraft" (Ref. 1).

The original contract for User Guides was supplemented to generate guides on eight additional aircraft, to introduce improvements in the guide format, and to correct specific aspects of the simulation model.

Since, the intent of the User Guide program is to assist the Forest Service in transferring the results of ongoing research to a field-useful form, the work is related to other programs at the Northern

Forest Fire Laboratory under separate contracts, notably the Experimental Tank and Gating System (ETAGS) Program (Honeywell) and Investigation of Rheological Properties of Aerial-Delivered Fire Retardant (Shock Hydrodynamics).

Work authorized in the supplemental program resulted in the generation of guides covering the eight additional aircraft and the release of format revisions on previous guides to (1) unify the ground-safety criteria and (2) incorporate technical data sheets documentating the specific field data input to the simulation model. The latter data potentially enables field personnel to identify aircraft or tank changes that might affect guide validity or to judge the similarity of tanking systems for which guides have not been developed.

Additional tasks resulted in the following:

- A correction to the simulation was introduced to reduce the apparent discrepancy between the predicted line lengths from gum-thickened and water-like retardants. Early work under the High Altitude Retardant Delivery Program (Ref. 2) had included a rule within the simulation that reduced the "percent recovery parameter" for aircraft other than the CL-215 when using gum-thickened retardants. No similar discounting was imposed on the routine dealing with water-like retardants. Re-examination of the rules for gum-thickened retardant using additional data furnished by the Forest Service showed that the discounting rule was not valid. Analysis of the previously published guides showed that only the Hemet Valley S2F was significantly affected by the change. This guide was subsequently revised and reissued. Although the elimination of the discounting rule brought the predicted patterns in line with real ones in a statistical sense, the simulation continues

to show a slight advantage to water-like retardants delivered at low altitudes that is not necessarily supported by field data. This anomoly is noted on the appropriate tables of the revised guides.

- A much improved subroutine to predict flow rate from tank geometry, door-opening rate, and vent parameters was developed. Test data from actual flow rates available at the end of the High Altitude Retardant Program showed that the Bernoulli simulation adapted from the original MacPhearson was in error for most tanks, which were acceleration-dominated rather than steady-state in their flow. The predictive routine was modified to choose between limit conditions of steady-state (Bernoulli) or acceleration-dominated flow based on tank geometry. In addition, a subroutine to estimate the pressure buildup due to venting and its effect on flow rate was added.

- Means were investigated to adjust Airtanker Guide performance data downward when tanks are downloaded, but no suitable technique was developed. Although a number of schemes to extrapolate downloaded performance were examined, none were capable of resolving performance over the full range of coverage levels. As a result, two separate guides were published on the Aero Union DC-6/7 tank, for 2400 gallons and 3000 gallons, respectively.

SECTION III

CORRECTION OF SIMULATION RULES DIFFERENTIATING BETWEEN RETARDANT TYPES

The objective of this effort was to re-evaluate the simulation rules for handling gum-thickened and water-like retardants on a comparative basis, particularly in the low-altitude, 100- to 500- foot range, based on Intermountain B-17 test data, and install appropriate changes. Using the new simulation rules, the adequacy of guidelines generated for the CL-215, Gilbertson DC-6B, Hemet Valley S2F, and Aero Union B-17 Aircraft was to be determined and any necessary corrections made.

BACKGROUND

Empirical simulation rules for handling gum-thickened retardants were developed under the High Altitude Delivery Program. Rules for handling water-like retardants were developed independently on the User Guides program. They were not, however, developed in a comparative sense. As a consequence there are some anomalies in their operation that tend to obscure differences in performance known to occur with drops at low altitude. Although an arbitrary change in the computerized rule equations might be made based on existing date, it is highly desirable to determine a more physically based and statistically satisfactory approach to display these differences.

The specific investigations include: (1) use of selected Intermountain B-17 drop data and card decks to enrich the calibration data base for rheological differences in the low-altitude range, (2) evaluation of Shock Hydrodynamics hypotheses for rheological differences in cross-range (or range development) as a method of organizing the rules

change, (3) recalibration of the program rules for gum-thickened retardants, water-like retardants or both in the low-altitude region to more properly reflect performance, and (4) development where necessary of improved performance guidelines for those aircraft studies under the contract.

Crossrange Development Rules

Initial evaluation of the increase in performance of water-like retardants relative to gum-thickened retardants at low altitudes centered on the rules in the simulation for generating the crossrange expansion. These rules were suspect for two basic reasons:

- Gum-thickened rules for crossrange expansion were generated prior to the availability of actual flow data; whereas water-like expansion rules were generated on a later contract using real flow data.

- There is a crossover in the rules governing crossrange development at 250 feet, below which water-like retardants are arbitrarily constrained to lesser expansion than gum-thickened types.

Regeneration of Expansion Rules for Gum-Thickened Retardant

The first of the possible sources of the problem was investigated by re-running the crossrange optimization program on Phos-Chek drops using real rather than simulated flow-rate data. The investigation used the same pattern data from CL-215 drops at 173-, 311- and 315-foot drop heights that were used in the original rule formulation (Figure 1). Using the same optimization procedure, the value of the normal crossrange parameter σ was increased and

decreased 2 feet from the previously defined rule. In each case, the value used in the current rule represented the best compromise in preserving the statistics of the simulated-to-actual pattern match. Tabular comparisons from the runs are summarized in the following:

- 300-foot Drops 4 and 17: For drop 4, the rule σ value provided the best fits. For drop 17 there was a slight improvement from increasing the σ value. Since these drops were nominally identical, it was concluded that no significant change in crossrange calibration was required from the use of actual flow rates in the simulation:

  - Drop 4, CL-215, 315-foot Drop Height

	Actual	σ = 22	σ = 24	σ = 26
Average 1	2.4	2.4	2.3	2.2
Average 2	.3	.7	.6	.6
Mean	-	-.0974	-.0906	-.0906
Variance	-	.4189	.3661	.3554
			Rule Value	

  - Drop 17, CL-215, 311-foot Drop Height

	Actual	σ = 22	σ = 24	σ = 26
Average 1	2.2	2.9	2.7	2.5
Average 2	.6	.7	.7	.7
Mean	-	-.0463	-.0432	-.0432
Variance	-	.6704	.5682	.5295
			Rule Value	

- 173-foot Drop 51: Similar performance was observed at 173 feet, as shown below. As a result, recalibration of crossrange expansion for gum-thickened retardant was not found to be a solution to the problem:

  - Drop 51, CL-215,, 173-foot Drop Height

	Actual	σ = 15	σ = 17	σ = 19
Average 1	3.3	3.2	2.7	2.6
Average 2	.7	.8	.8	.6
Mean	-	-.0325	-.0325	-.2075
Variance	-	.7087	.6321	.5073
			Rule Value	

Check of Crossrange Expansion Rules Using Intermountain B-17 Data

Figures 1 and 2 show the crossrange expansion rules contained in the simulation to distinguish between gum-thickened and water-like retardants. Experience has shown that the value σ, normal crossrange, has a far greater influence on significant coverage than the semi-crossrange parameter. There is, however, a crossover point on the two rule curves at about 250 feet that implies a slightly greater separation rate on gum-thickened retardants at low altitudes. This probably is an anamoly of the rules and the relatively sparse data suitable for use in a calibration sense. It is more likely that response curves for the two materials converge. Since the major discrepencies in line length appear to relate to gum-thickened retardants at moderate altitudes, the values of both parameters were examined for their effect on simulated patterns. Match data are

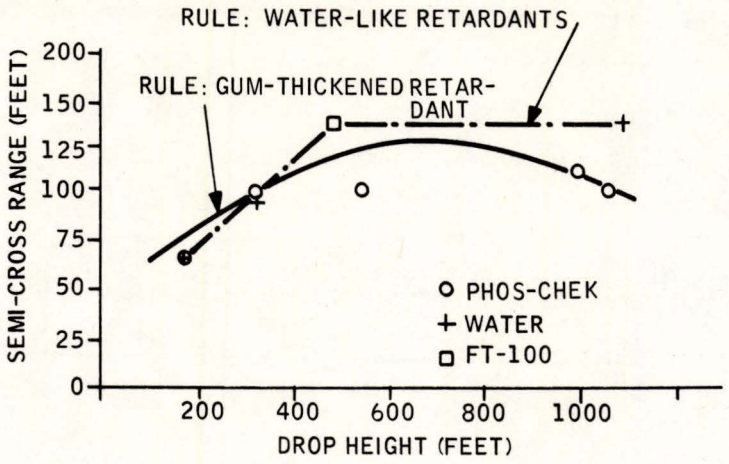

Figure 1. Comparison of Semi-Crossrange Values for Gum-Thickened and Water-Like Retardants

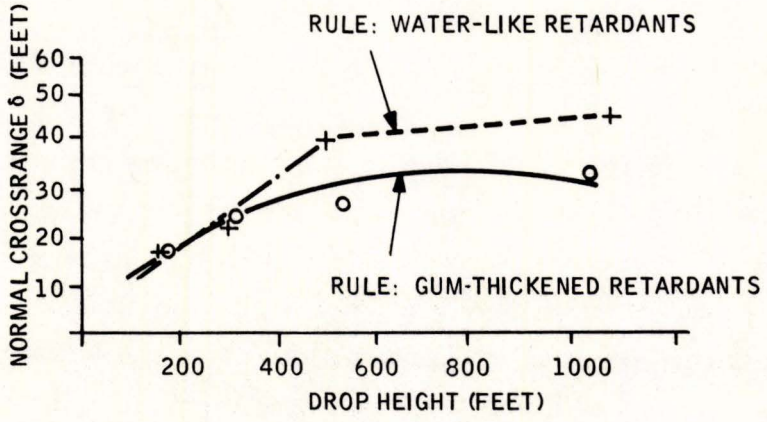

Figure 2. Comparison of Normal Crossrange Rules for Gum-Thickened and Water-Like Retardants

presented in Appendix A on the three drops, with data sets complete enough for use in a calibration sense.

The surprising results were that simulated patterns run in the Modified Retard program predicted continuous line lengths well for their equivalent actual patterns. Figures 3 through 5 show these results. Only at 400 feet die the simulation underpredict the length at 2 gpc (gallons per 100 ft ^{2}) significantly. As a result, the differences did not appear to result from the crossrange expansion rules per-se.

PERCENT RECOVERY RULES

The difference between the PATSIM simulation used to generate patterns for calibration in the modified RETARD and that employed as a stand-alone simulation is that the amount of retardant recovered

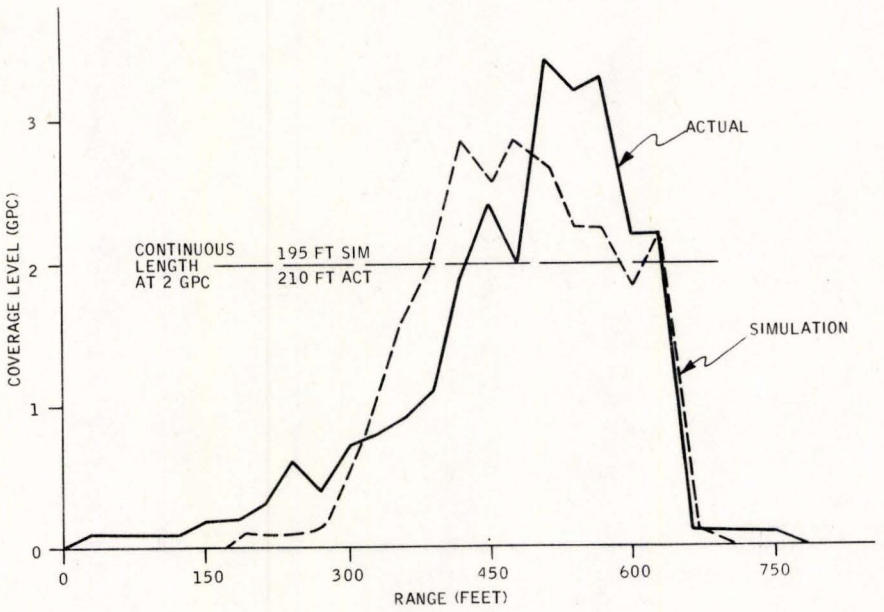

Figure 3. Pattern Cross Sections for Intermountain B-17 Drop 31 (drop height 214 feet, Phos-Chek Retardant)

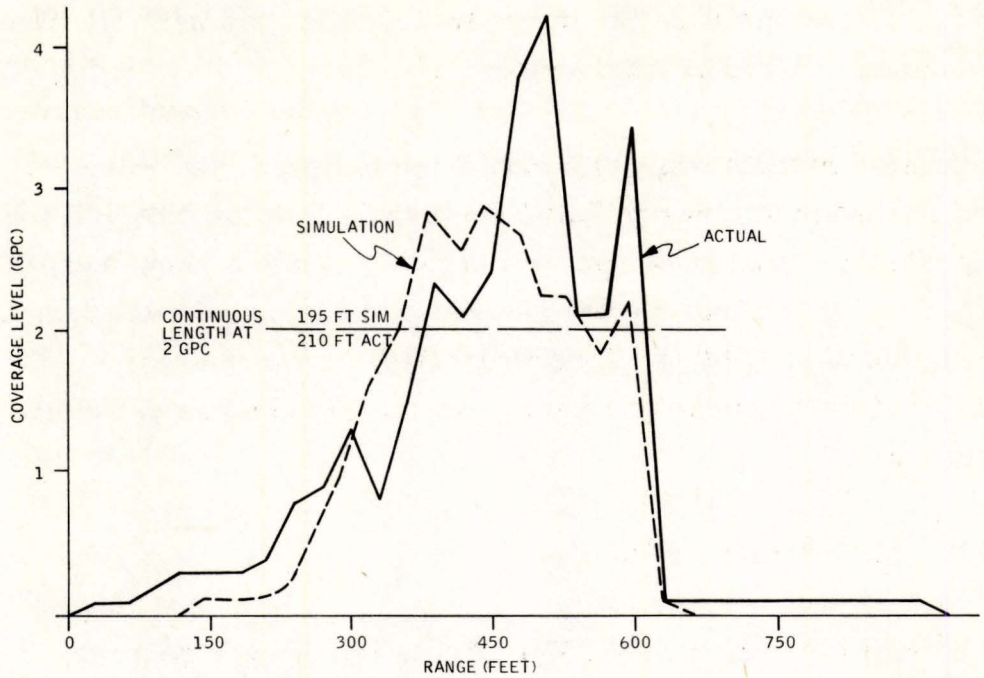

Figure 4. Pattern Cross Sections for Intermountain B-17 Drop 29 (drop height 194 feet, Phos-Chek Retardant)

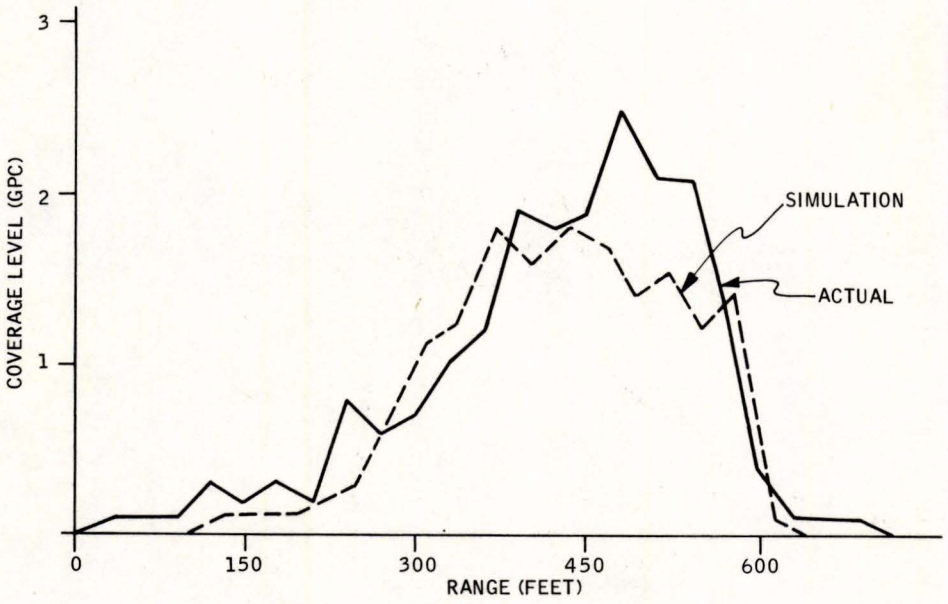

Figure 5. Pattern Cross Sections for Intermountain B-17 Drop 30 (drop height 393 feet, Phos-Chek Retardant)

is always adjusted to the actual pattern so that these values do not confound the parameters of interest. On the other hand, the stand-alone model employs empirical rules to predict the percent recovered. This difference caused the considerable discrepancy in pattern match between the two simulated patterns and resulted in an under-prediction of line length for gum-thickened retardants.

The specific rule at issue is a somewhat arbitrary reduction of the recovery percentage when gum-thickened retardants are dropped from aircraft other than the CL-215. This rule was introduced in the High Altitude Retardant Program based on data suggesting, at that time, that recovery percentages from the CL-215 were higher than those of other aircraft. No similar discounting of the recovery rule was included for water-like retardants. The percent recovery rules are shown in Figure 6.

Note that the arbitrary discounting of "other aircraft" tends to reduce the amount of retardant in the pattern considerably. Figure 7 shows a scattergraph of the recovery percentages for all gum-thickened retardant drops in the Intermountain B-17 test series. The graph shows little reason to discount the aircraft from the CL-215 rule. By contrast, Figure 8 shows that the recovery percentage does over-predict recovery for the water-like retardants for this aircraft.

Review of the analysis that lead to the discounting of other aircraft showed that it was a somewhat questionable assumption, based in part on issues later resolved as to the actual capacity of CL-215 tanks. The discounting was simply removed from the program to accommodate the observed problems.

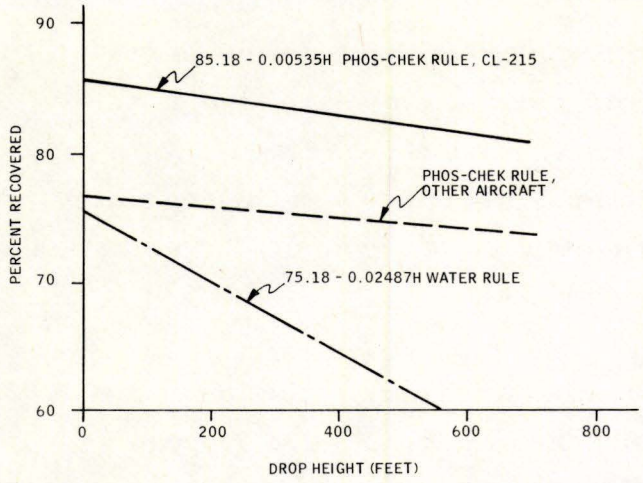

Figure 6.
Percent Recovery Rules Used in the Simulation

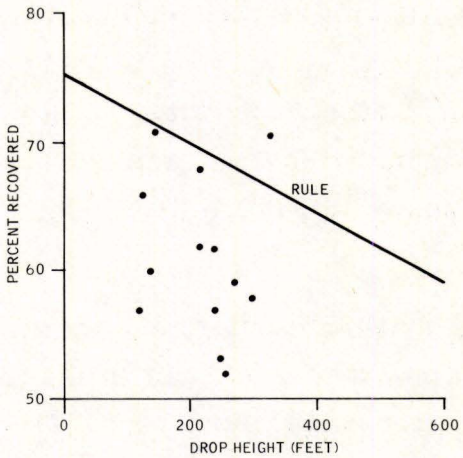

Figure 7.
Percent Recovered for Gum-Thickened Retardants, Intermountain B-17 Tests

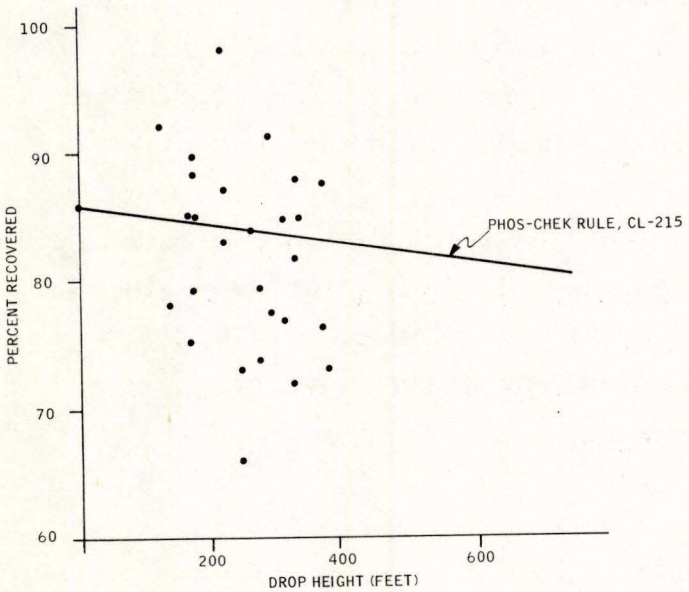

Figure 8.
Percent Recovered for Fire-Trol and Unthickened LC, Intermountain B-17 Tests

The effect of these results on existing guidelines is discussed in the following paragraphs.

- CL-215 — The analysis showed no basis for changing guide lines on the CL-215. Original data were run without the "other aircraft" rule and recalibration showed no basis to change treatment of this aircraft.

- Gilbertson DC-6B— The Gilbertson DC-6B was used as a checkpoint in establishing the original rule set and was to a certain extent responsible for the "other tank" discounting rules. It is in fact listed in the computer program as a DC-6B subroutine before it was generalized to other aircraft. There is not now sufficient contradictory data to justify a change in the DC-6B guides.

- Hemet Valley S2F — The Hemet Valley S2F baseline data were re-run using undiscounted parameters, and the results are being included in a new edition of the basic guide. The most striking difference is in the single-compartment footprint and its comparison with the water-like retardants. Figure 9 shows the effect of the change on estimated tank performance. The effect is far less pronounced on multiple-compartment drops. In general, the change in rules does not affect usage guides significantly — the errors introduced are conservative. The change does correct a misleading conclusion regarding relative capabilities of gum-thickened, and water-like retardant when used in this aircraft. Figure 10 shows the predicted changes in relative line length at two coverage levels and compares them to those predicted for water-like retardants.

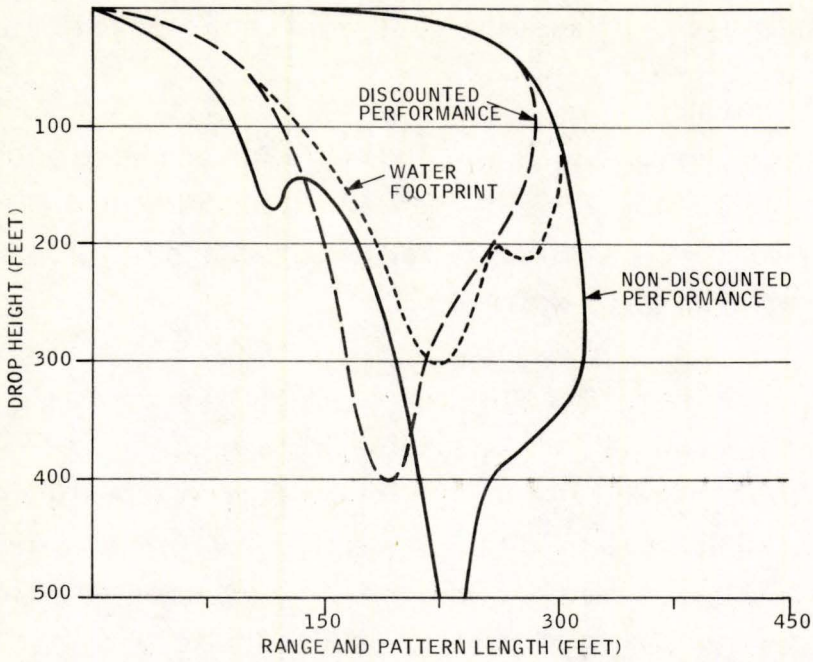

Figure 9. Effect of Percent Recovery Rule on Patterns from the Hemet Valley S2F (Phos-Chek single-compartment drop, coverage level 1)

- Aero Union B-17 — The Guideline data for the Aero Union B-17 was not rerun based on observations of the effect of recovery rules on larger tanks. The effect of the rule change is most pronounced on small tanks at low altitudes. As a result the general guides are not significantly changed in terms of reviewing usage strategies. The guide data were checked at the time of their generation to estimate conformance to test data. They appeared to be reasonable for general usage. The effect of the rule change will not reorder the basic strategy recommendations.

- Intermountain B-17 — The correction of the simulation corrects the order of effect for water-like and gum-thickened

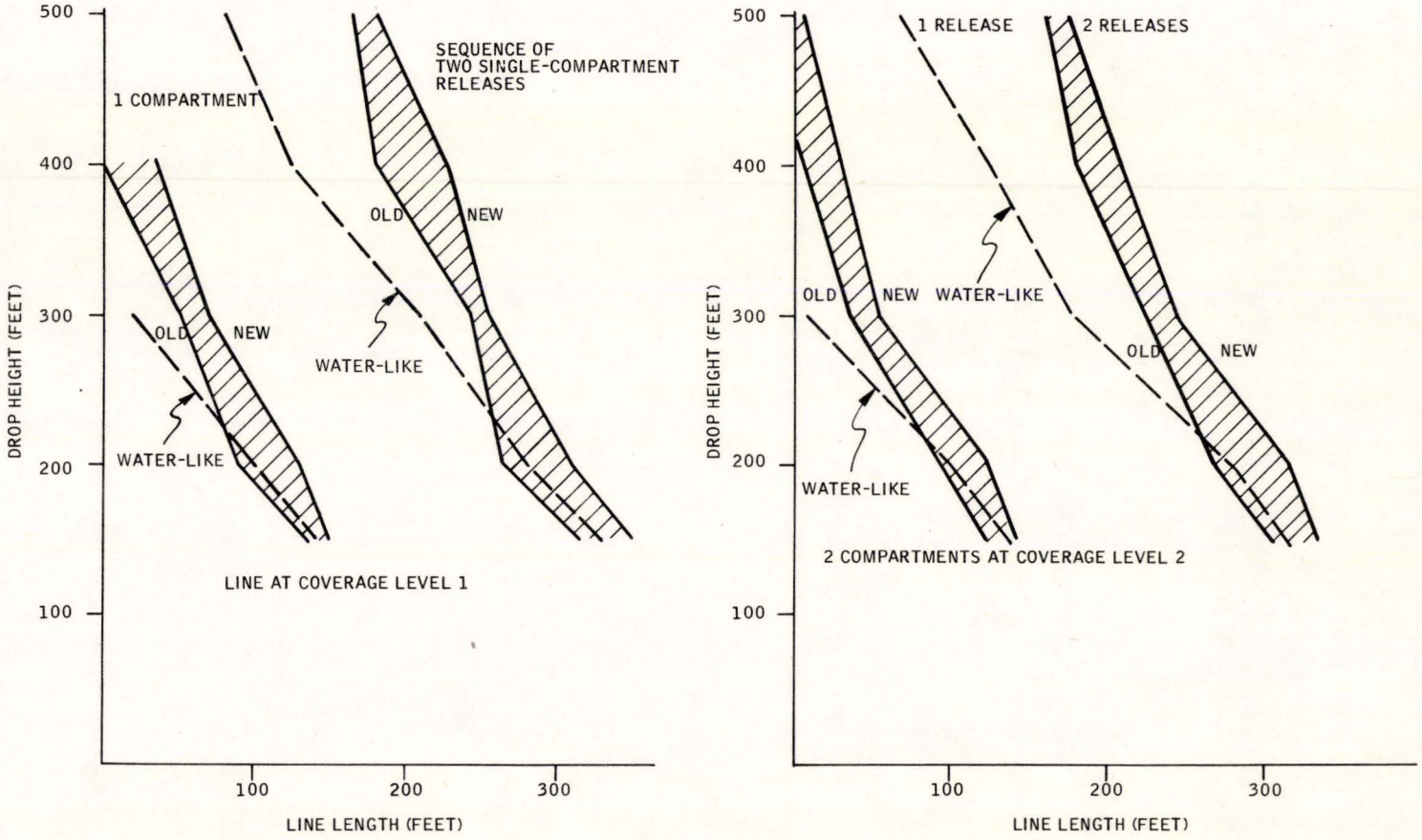

Figure 10. Effect of Percent Recovery Rules on Line Length, Hemet Valley S2F Tests

retardants as used in the PATSIM program. It did not, however, elevate single-compartment line lengths at 2 gpc to levels actually encountered in the test drops. The predicted data are shown against scattergraphs of actual data in Figure 11.

From a modeling standpoint, there is little basis to justify further changes from data on a single aircraft. Although there is some reason to believe that water-like retardant percent recoveries at 100 feet contribute to the overestimation of line length at that point, no similar arguments can be advanced for the under-prediction of line lengths for gum-thickened retardants. The significance of this under-prediction is not thought to be great, since (1) it is safely conservative, and (2) an arbitrary increase in line length would not fundamentally change the best strategies decisions. The causes of this discrepant performance are best left to definitive studies of tank performance on the ETAGS program, if fundamental changes to the simulations are required. The discrepancy is recognized in the guides on the Maximum Line Length-Tables by the following note:

> Note: Low-altitude line lengths tend to show a slight advantage for water-like retardants that is not necessarily supported by field data. The advantage of gum-thickened over water-like retardants increases rapidly under less-than ideal conditions.

PROGRAM CHANGES

Pursuant to the above studies, the RETARD program previously employed to compare simulated with real patterns, was modified to

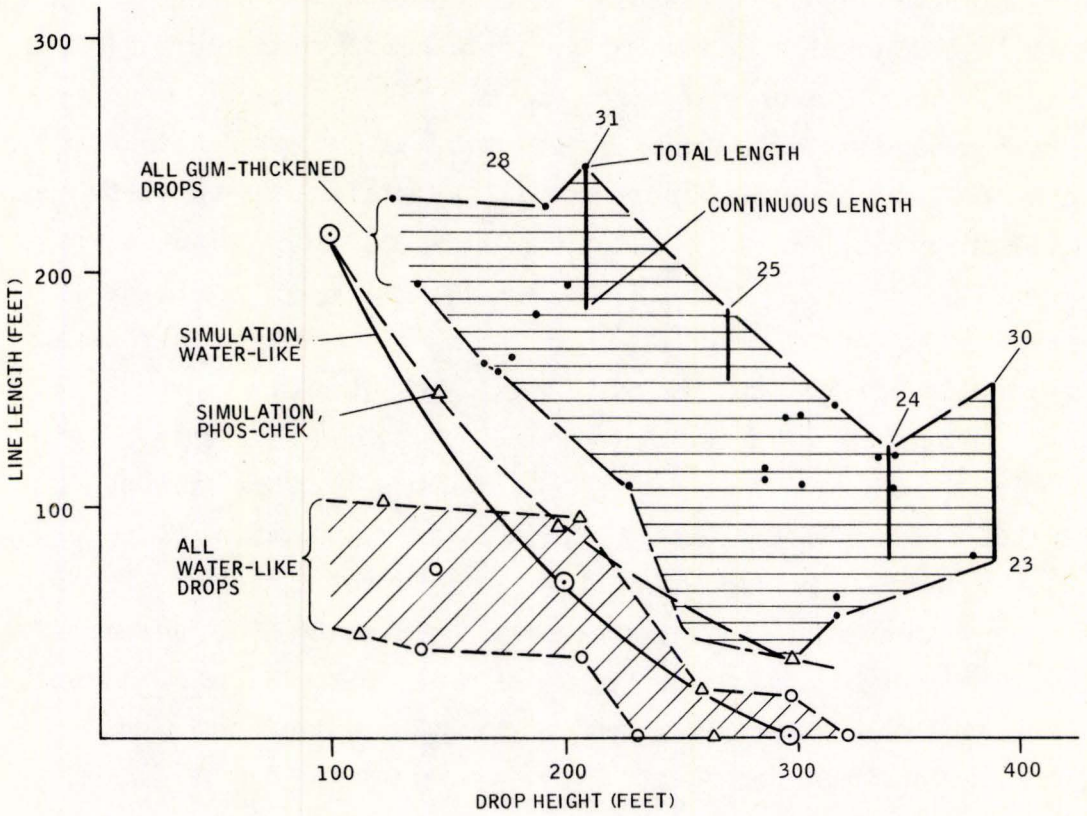

Figure 11. Predicted and Real Line Lengths for Intermountain B-17 (USFS data, 2 gpc)

permit a direct comparison between two actual patterns. This technique enables generation of absolute differences between distributions and analysis of the significance of any frequency data contained in the pattern. Figure 12 examines the contention that water-like and gum-thickened retardants differ in the value of the marginal distribution. It shows the Fourier power spectrum of the difference between two identical drops (Phos-Chek), and one Phos-Chek drop and an unthickened Fire-Trol LC drop. Difference values from replica patterns are on the order of 10^{-6}; i. e., this is the approximate noise level in the comparison of like patterns. The noise in comparing different retardants is on the order of 10^{-5}. They are greater primarily in the amount available (axis crossing), in the pattern length (620 feet), and to a lesser degree in the fore and aft distribution around the pattern centerline. The latter difference can be caused by wind effects on the pattern tending to skew it or by the method of aligning the patterns before differencing. The data support the contention that the primary difference in marginals between thickened and unthickened agents is the amount recovered.

Figure 13 shows the difference data between the reference drop (31, Phos-Chek) and a second drop of water-like retardant. In both cases the difference data performed similarly. Figure 14 provides a comparison of the power spectrum that supports the similarity of performance of different gum-thickened retardants. The third comparison shows, by contrast, the effect of altitude (a parameter of known significance) on the power spectrum. In this case the differences in power spectrum are generally two magnitudes higher, on the order of 10^{-4}.

The ability to employ this technique more precisely requires that the simulation incorporate a means to rotate the patterns and reduce wind skew, a source of some of the spectral power. This change is being

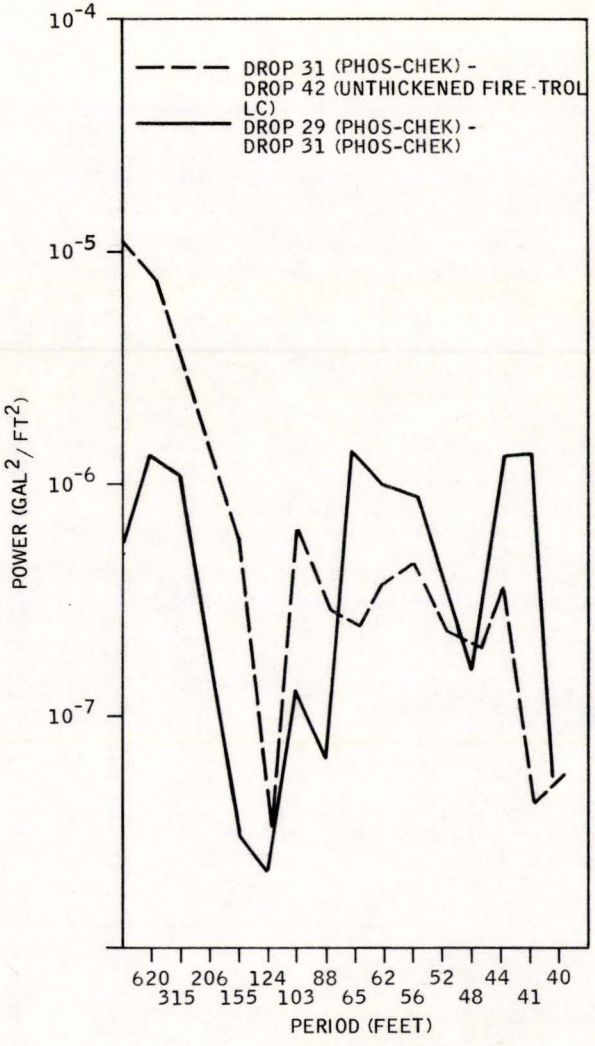

Figure 12. Power Spectrum of the Difference Data for Drops of Two Different Materials

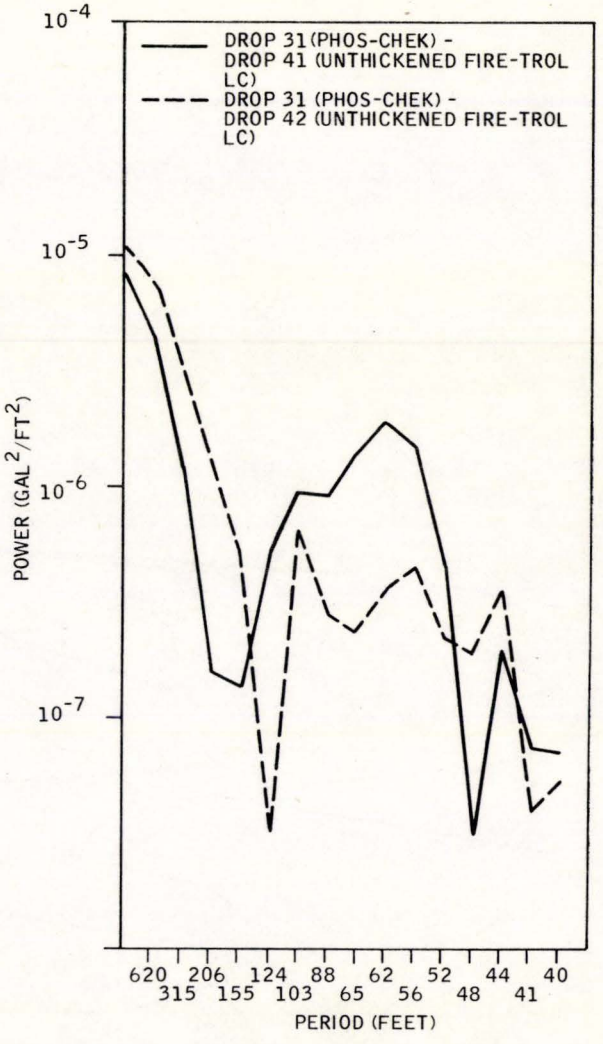
DROP 31 (PHOS-CHEK) - DROP 41 (UNTHICKENED FIRE-TROL LC)
DROP 31 (PHOS-CHEK) - DROP 42 (UNTHICKENED FIRE-TROL LC)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
POWER (GAL^2/FT^2)
620 206 124 88 62 52 44 40
315 155 103 65 56 48 41
PERIOD (FEET)

Figure 13. Two Comparisons of Difference Data in Drops of Gum-Thickened and Unthickened Retardants

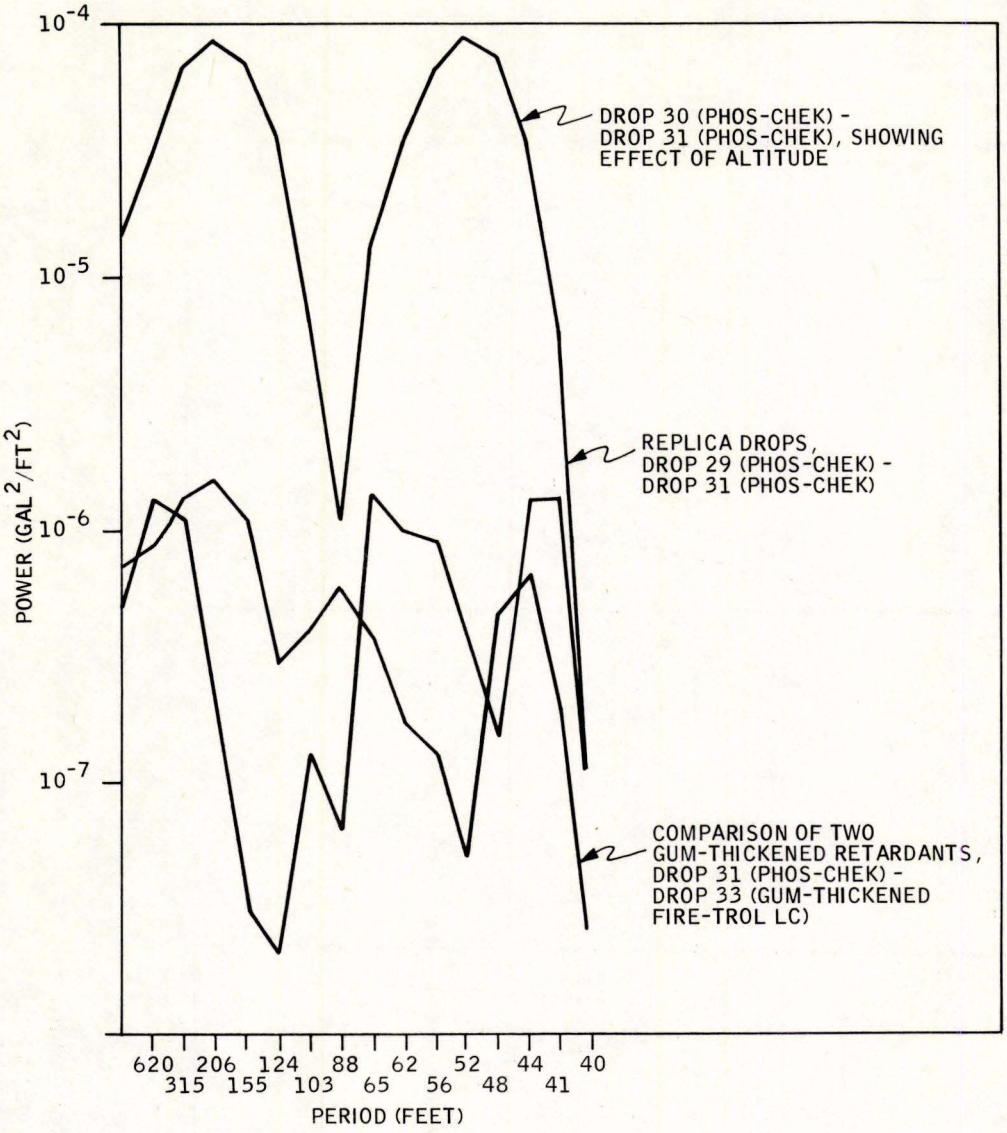
10^{-4}
10^{-5}
10^{-6}
10^{-7}
POWER (GAL^2/FT^2)
DROP 30 (PHOS-CHEK) - DROP 31 (PHOS-CHEK), SHOWING EFFECT OF ALTITUDE
REPLICA DROPS, DROP 29 (PHOS-CHEK) - DROP 31 (PHOS-CHEK)
COMPARISON OF TWO GUM-THICKENED RETARDANTS, DROP 31 (PHOS-CHEK) - DROP 33 (GUM-THICKENED FIRE-TROL LC)
620 315 206 155 124 103 88 65 62 56 52 48 44 41 40
PERIOD (FEET)

Figure 14. Comparisons of Similar Drops and the Effect of Altitude

incorporated under the ETAGS program. The basic techniques developed under this contract represent another tool for interpreting parametric pattern differences and their significance.

SECTION IV

DEVELOPMENT OF A SUBROUTINE FOR FLOW-RATE PREDICTION

One task of the contract required investigation of means to correct the flow-rate-predicting subroutines of the PATSIM program so that they reasonably predict tank performance from knowledge of the tank's geometry, venting and door-opening parameters. Specifically:

> "Investigate the possibility of achieving adequate flow-rate predictions from tank geometry by simple modifications to the Bernoulli simulation subroutines as a nonsubjective method of generating guideline material where float data do not adequately reflect total tank performance."

The subroutines of the PATSIM program that predict volume flow rate from tank geometry and door-opening rate did not predict flow rate adequately for many tank configurations. The lack of a predictive subroutine to back up measured flow data in the generation of guidelines was a major problem when measured data did not adequately reflect tank flow. This condition occurs when float instrumentation cannot track the flow of significant retardant quantities (viz, the last one-third of the retardant evacuated from the Gilbertson DC-6B) or when inadequate venting causes the fluid surface to halt, resulting in pop-bottling (as in the Hemet Valley S2F).

RESULTS AND CONCLUSIONS

The Bernoulli simulation of flow originally adapted from MacPhearson was substantially revised to operate in one of two limit modes:

(1) A free-fall mode in which fluid velocity is described in terms of acceleration and time, or

(2) A steady state mode in which fluid velocity is described by the Bernoulli equation in terms of the hydraulic pressure head.

The program calculates flow using both mode equations, and selects the lower for use in the next integration step. Consequently, it is a rough numeric approximation to the partial differential equations governing fluid flow. In the process, an algorithm was added for predicting the negative pressure build up in the top of the tank as a function of venting parameters and employing this pressure to modify the flow rate. Theoretically, the program can recognize conditions leading to pop-bottling, flag them, and estimate the flow rate until evacuation is complete.

The program as modified produces a far better flow-rate prediction than the original Bernoulli simulation, as shown in Figure 15 for the CL-215 which, due to its complex geometric changes, is a very difficult tank to simulate.

The tank is best simulated as an acceleration mode, only. Introduction of the choice of modes appears to degrade the prediction in this case. The error is partly related to the definition of effective door-open areas for the tank and partly symptomatic of the problem of handling multiple transitions in tank geometry in a fully automated program. A similar condition appears in the Aero Union B-17 salvo simulation (Figure 16). Conversely, the choice routine produces a remarkable correspondence to the Aero Union trail drop (Figure 17).

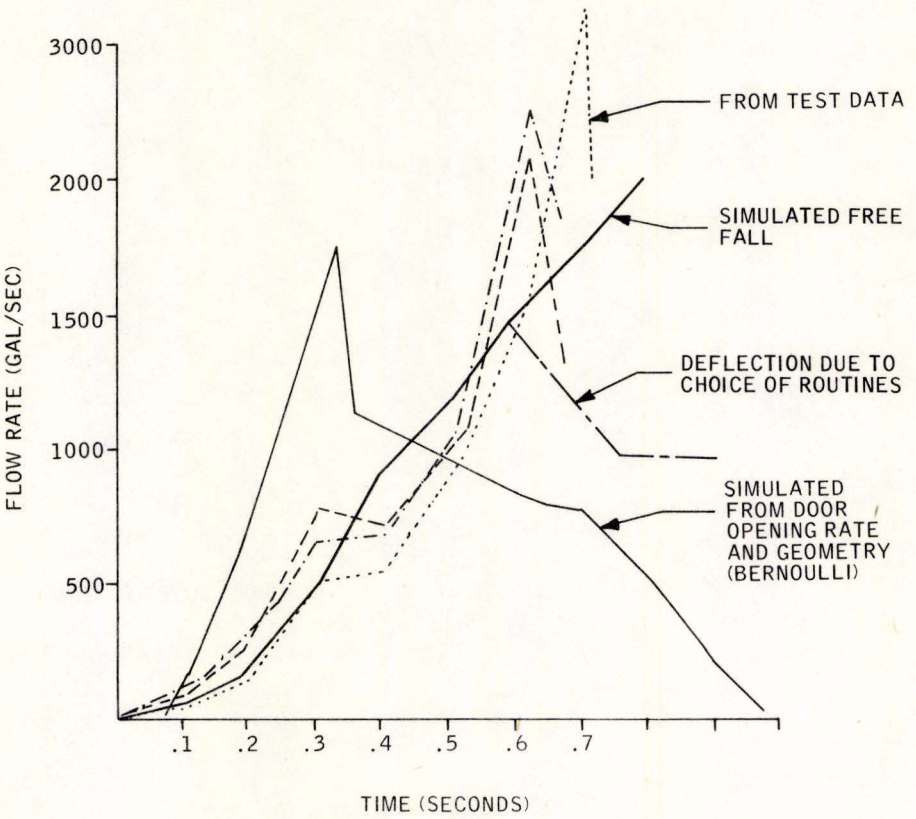

Figure 15. Comparison of Simulated and Measured Flow Rate for CL-215

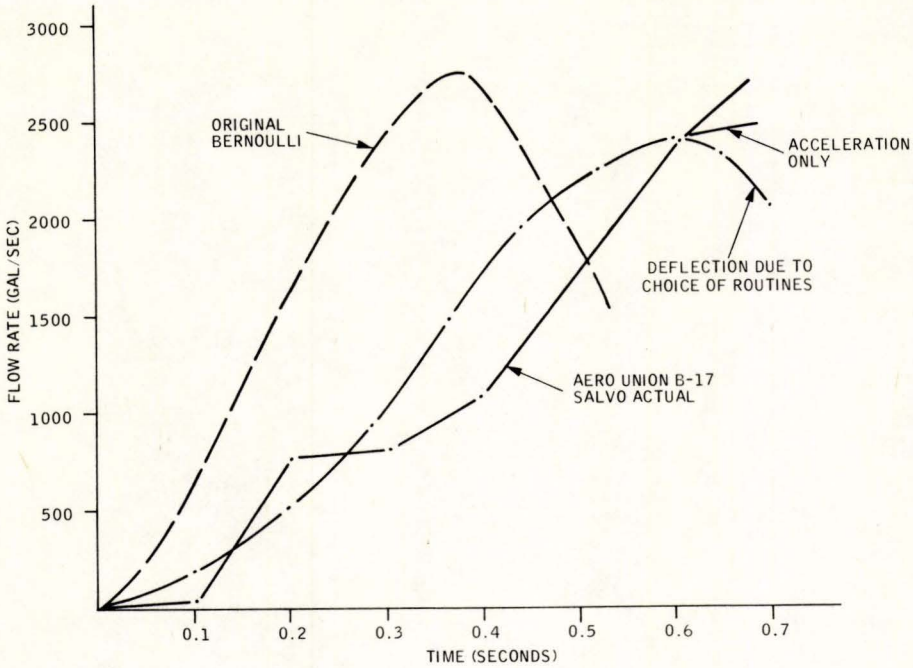

Figure 16. Comparison of Simulated and Actual Flow Rates for Aero Union B-17 Salvo Drop

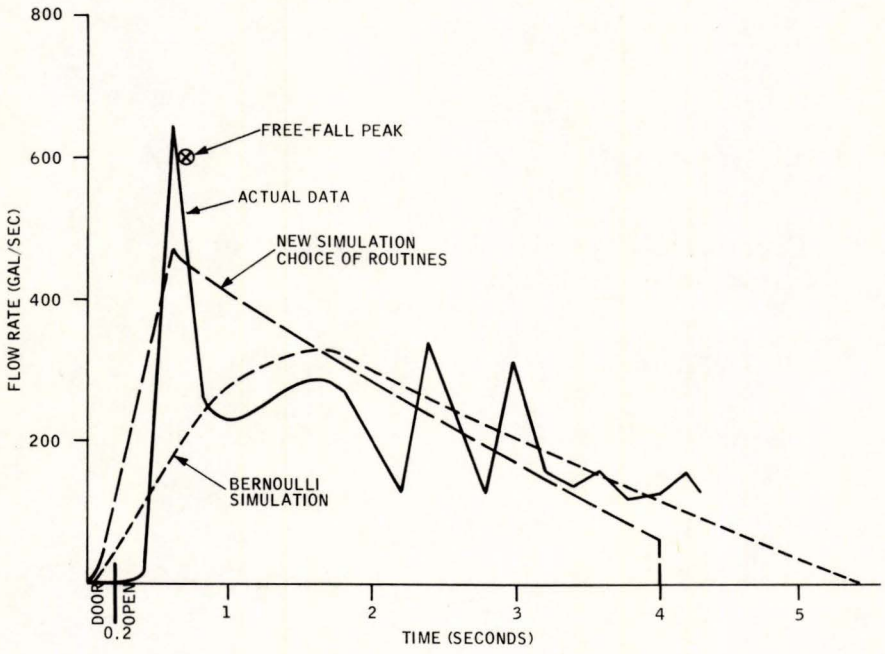

Figure 17. Comparison of Simulated and Actual Flow Rates for Aero Union B-17 Trail Drop

As a result of the above, it is concluded that the revised simulation can be used to predict flow rate but that intelligent manipulation of program flags by the operator will produce the best match by selecting the appropriate rules for the particular tank. Further analysis indicates that a more precise definition of tank geometry is probably required to achieve greater accuracy.

Introduction of the pressure predictor contributes to the apparent error in terminal tank performance but shifts the flow rate prediction through the bulk of the drop closer to the measured value. Peak pressures predicted are on the order of those observed: B-17 salvo 0.87 psi versus 0.85 psi observed; Hemet S2F 0.77 psi versus 0.5 psi observed. These results were achieved without special effort to calibrate the simulations.

Although the program is set up to recognize conditions of tank stoppage due to pressure, the best program for most prediction purposes enters an oscillation about the stopping point. Correction of this issue was beyond the scope of this task and properly should follow the availability of better data for calibrating effective door area and the pressure prediction routine.

PROGRAM OPERATION CHANGES

The program to operate the revised simulation (summarization in Appendix B) includes several operational changes; they are:

A(54), a flag to stop the run after the flow rate is determined. A(54) = 1 stop. A(54) = 0 continue through pattern simulation.

A(55), selects Bernoulli simulation (=0); acceleration only (=2); or, choice of routines (=1).

A(56), implements the pressure routine (=1) or conducts the computation without pressure (=0).

Input variables added are:

26 FLVENT-Length of tank vent (ft); initial value zero
27 AVENT - Area of combined vents (ft^2); initial value zero
28 DVENT - Diameter of vent (ft); initial value zero
29 FNVENT - Number of vents; initial value zero
30 TTAB - Flag selects option to use tabular input of door angle versus time if set; initial value zero

The door-angle-versus-time table was introduced to eliminate the error contributed by a polynomial fit and to make use of measured data in other simulations. To employ this routine the TTAB variable must be on one card with the table immediately following. There is one table entry per card, with the numbers of cards specified in TTAB. Table entry format is as follows:

Columns 1-10: Time (seconds)
Columns 11-20: TMPS, door opening angle (degrees)

The variables PSII and THMAXI must be entered when using this option. They are related as follows:

THETA = TMPS + PSII with the maximum value of THETA = THMAXI

DISCUSSION

In the late stages of the Extended High Altitude Retardant Drop Study, flow-rate data became available on actual evacuation from

the CL-215. These data showed that the Bernoulli simulation of flow, taken from MacPhearson, differed substantially from the actual flow rates measured in tank evacuation. This discovery left the flow simulations of the program in doubt. It was subsequently changed to work from measured data for pattern prediction purposes on the original User Guide Programs. During the course of investigating flow rates for other aircraft, it was found that flow rates in most instances closely resembled those occuring if the fluid velocity was assumed to follow a free-fall law. As a result, the possibility of revising the flow rate simulation, while retaining its basic simplicity, was recommended.

Examination of the Bernoulli Simulation

The Bernoulli equation calculates the difference in velocity between the top surface of the tank and flow emanating from the bottom. It describes a steady-state condition in which the acceleration term of the source partial differential equation is negligible:

$$\frac{\partial \mu}{\partial t} + \frac{\mu \, \partial \mu}{\partial x} = g \qquad (1)$$

where μ is the velocity and X is the distance (head height). When the acceleration term, $\frac{\partial \mu}{\partial t}$, is negligible, the integral of the resulting ordinary differential equation is the familiar form of Bernoulli:

$$V_E^2 - V_Z^2 = 2gh \qquad (2)$$

where V_E is the velocity of efflux, V_Z is the velocity at the top of the fluid, and h is the hydraulic head.

The equation programmed by MacPhearson and used in the simulation was further modified by applying the conservation law

$$V_E A_E = V_Z A_T \tag{3}$$

where A_E is the exit area and A_T the top area of the fluid. Thus

$$V_Z = V_E \frac{A_E}{A_T}$$

By substitution

$$V_E = \frac{2gp}{1-R} 2, \tag{4}$$

where R is $\frac{A_E}{A_T}$

In previous work, Honeywell had expanded the pressure term (2gh) to consider pressurized tanks (and conversly the potential to evaluate the buildup of pressure due to evacuation) to the form

$$V_E = \frac{2g \rho h + p}{(1 - R^2) \rho} \tag{5}$$

where ρ is fluid density, and p is pressure

There is one notable difficulty with the above equation. That is, as the ratio of areas approaches unity as it does in most tanks with the doors fully open, the velocity rises rapidly to an indeterminant; i. e., the flow is no longer "steady-state" but acceleration-dominated. From the conservation equation, the statement simply means there is no difference between V_Z and V_E due to hydraulic pressure. (The rapid exponentiation was simply disallowed in the program by maintaining a vena constricta value, α, that precluded area

equivalence.) In the case of the fully opened tank, the fluid velocity is not determined by hydraulic pressure but governed by free-fall physics. It becomes a Newtonian tank.

Newtonian and Bernoulli Comparison

From the source equation (1), if the pressure term is negligible, the partial of acceleration integrates simply to g. Thus, as we would expect, the second determinent of ejection velocity is free-fall acceleration.

If tank evacuation were considered to be free-fall as in a straight-sided tank with full bottom area, and unrestrained doors, the ejection velocity at any time would be

$$V_E = 2g\ \Delta h \qquad (6)$$

where Δh is the loss of head, or distance the fluid has fallen.

This equation is consequently the mirror image of the Bernoulli equation, as was the measured to the predicted flow from the CL-215:

$$V_E = 2gh \qquad (7)$$

To test this hypothesis, actual data on Aero-Union B-17 drops were employed. This tank has a very fast door, a relatively simple geometry and adequate venting. Results were highly satisfactory in that the change to a free-fall law brings the predicted flow closely in line with actual data. The free-fall rule also corrects the form of the predicted CL-215 simulation.

An Approximate Method for Combination

Tanks in the field represent both acceleration- and pressure-dominated configurations with regions of mixed contribution; thus a method of modeling the transition was desired, without the complexity of dealing directly with the partial differential equations. In the approximate method selected, both the Bernoulli velocity and free-fall velocity are calculated, and the lower is always selected; i. e., both are viewed as limit velocities. Initial conditions for each calculation are those resulting from the prior computation step.

In this scheme, the velocity V_Z at the top of the tank is not solely determined by the velocity of efflux. There will exist an initial V_Z at the top of the tank when the transition occurs; this is a "velocity head" in addition to the pressure head. To introduce this provision the Bournoulli equation was reprogrammed, closer to its original form:

$$V_E^2 = \frac{2gph - 2P}{\rho} + V_Z^2 \qquad (8)$$

The top velocity, V_Z, is then redefined as:

$$V_Z = V_{Z0} + V_E \frac{A_E}{AZ} \qquad (9)$$

Since in short times (as in the initial tank opening) all flow buildup is limited by acceleration, this revision produces a residual velocity at tank evacuation even for tanks of considerably restricted door area -- ejection velocity does not become zero at the end of the tank release. (This is supported by data on the Aero-Union B-17 trail door.)

The free-fall equation was also elaborated to include pressure-related acceleration and is defined for the program as

$$V_E = V_{ZO} + \Delta t \quad G + \frac{P}{\rho h} \tag{10}$$

where the term $\frac{P}{\rho h}$ is the acceleration due to pressure, normally negative in an unpressurized tank.

Pressure Simulation

In tank evacuation, vents at the top allow air entry to replace the volume of fluid lost. In most cases the vent area is a restriction usually closed by a spring-action flapper valve. Since air passing through a restriction undergoes a pressure drop, a negative pressure develops at the top of the tank. This pressure, as shown above, can be expected to modify flow from the tank with a significance that is difficult to determine intuitively. For example, a measured negative pressure of 0.85 psi in the salvo drop of the Aero-Union B-17 shows little effect on the resulting flow. But a negative pressure of 0.5 psi reduced flow from the shorter Hemet Valley S2F tanks, causing pop-bottling (Reference 1). The reason for this variation in pressure related performance is apparent in the above equations. Specifically, the significance of the negative pressure depends on its relationship to the velocity head at the time it develops.

To include the dynamic effects of the developing pressure, a means of predicting it was incorporated in the model.

Pressure Algorithm

The pressure routine programs an equation from Reference 4 calculating the change in pressure across a duct. The basic equation is

$$P = \frac{L f^1 RT (M^1)^2}{40 p (D)^5} \quad (11)$$

where

P = pressure drop (psf)

L = length of vent (ft)

M^1 = mass rate of flow = $\rho_{air} \times Q_{m-1} = 0.0871 \; Q_{m-1}$

Q_{M1} = volume flow rate (ft^3/sec)

p = mean pressure in the line (psf) $\approx$ 14.7 (144)

D = equivalent diameter of vents = vent area/.7854 (ft)

f^1 = friction factor = 0.038 (assumed from text tables)

R = a gas constant $\approx$ 1545 (assumed from text tables)

T = mean absolute temperature $\approx$528K

Combining constants provides the following relationship:

$$P = \frac{0.00278 \; L \quad Q_{(m-1)}^{\;2}}{D^5} \quad (12)$$

Thus, the instantaneous pressure is expressed as a function of the demand and the dimensions of the ductwork, and the demand comes from the cubic feet of retardant dropped in a given time increment. Note that the dimensions of the vent are assumed to be constant.

Actually, this is not always the case in that an initial pressure buildup is required to open the vent's flapper valves, which in some cases provide a pressure-variable opening.

In initial runs, total pressure was defined as the initial pressure plus the instantaneous ΔP from demand. This resulted in tank stoppage almost immediately. It is tantamount to assuming that the system has no recovery. Actually, the pressure differential across the vent would cause an inflow until equalization. If we assume that recovery is instantaneous, total pressure is equal to ΔP. When programmed with this assumption, pressures developed in the simulation are of the right magnitude and appear to be within calibration limits of the data.

Alternative Models

The particular model for pressure has certain inherent difficulties, primarily in its dependence on the length of the vent. Its selection was in part influenced by early concern with the complex and lengthy ventwork on the Hemet Valley S2F.

An alternative view to the pressure model employs the familiar Bernoulli model, used in an aerodynamic way. In this case the pressure is viewed as a velocity-related term. Specifically

$$\Delta P = 1/2\ \rho V_o^2, \text{ or for air; } 1/2\ (.002378)\ V_o^2 \qquad (13)$$

Since the velocity of the air is related to fluid flow by the conservation law, the reduced form of the equation is:

$$V_o = \frac{4Q_{(m-1)}}{\pi D^2} \qquad (14)$$

$$\Delta P = \frac{.0019275\ \left[Q_{m-1}\right]^2}{D^4} \qquad (15)$$

Note that Equations (12) and (15) are similar except for the inclusion of the resistance due to duct length. They are in fact equivalent when the length-to-diameter ratio of the vent is about 0. 3.

Tank Stoppage

A programming rule to flag tank stoppage was incorporated in the program. Essentially, if the velocity of efflux goes to zero, the condition is printed. The tank will then be evacuated by fluid displacement as a bubble rises from the bottom. Since bubble travel is described by the Bernoulli equation, the program also defaults to Bernoulli computations of efflux velocity until the tank empties. This rule is strictly an approximation to assist in generating a flow rate when float measurements are not adequate to predict patterns due to pop-bottling release.

Although the stoppage subroutine works on a strict Bernoulli tank, it falls short of working in the fully automated system. When there is a choice of routines between acceleration and Bernoulli-dominated flow, the program enters an oscillating mode as it approaches the stopping point. This condition can be eliminated by hand inputting limits based on known tank characteristics, but it defeats full automation of a tank evaluation system. Only limited attempts to damp this oscillation were made since further work was beyond the scope of the task as proposed.

Evaluation of the Choice of Routines

In the range of possible tank configurations, several paths can be taken in program execution. All tanks initially operate as acceleration-based systems. Some, such as the Aero-Union B-17 salvo, complete their evacuation without a shift to the Bernoulli or

restricted flow mode. Others quickly revert to restricted flow (B-17 trail), and some (based on geometry) undergo several transitions. Some typical geometric transition patterns are shown in Figure 18.

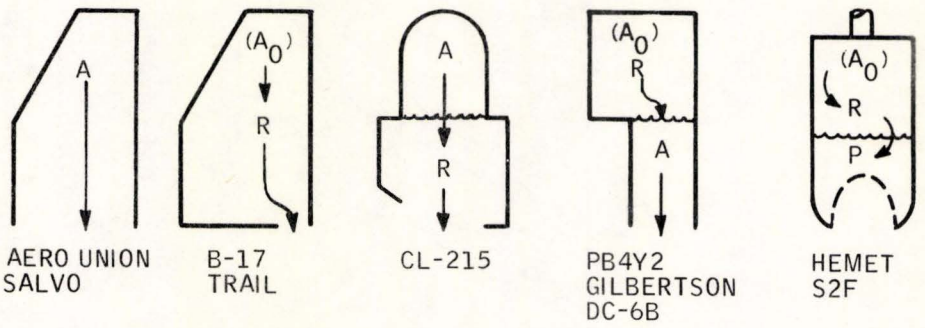

Figure 18. Variety of Flow Transitions in Known Tanks

The best performance of the simulation occurs if the transition pattern is prescribed in advance. The effects of the simulation rules on CL-215, Hemet Valley S2F, and AU B-17 flow in both trail and salvo modes are shown in Figures 19 through 22.

To introduce further refinement, certain other aspects of the model require evaluation, and these data will be available in the ETAGS study. Specifically, the determination of the effective door area during dynamic opening and data suitable to calibrate the pressure routine should be available. In terms of the door area issue, the value α, a derating factor on effective area, was set at unity for the simulation runs shown in the example set above.

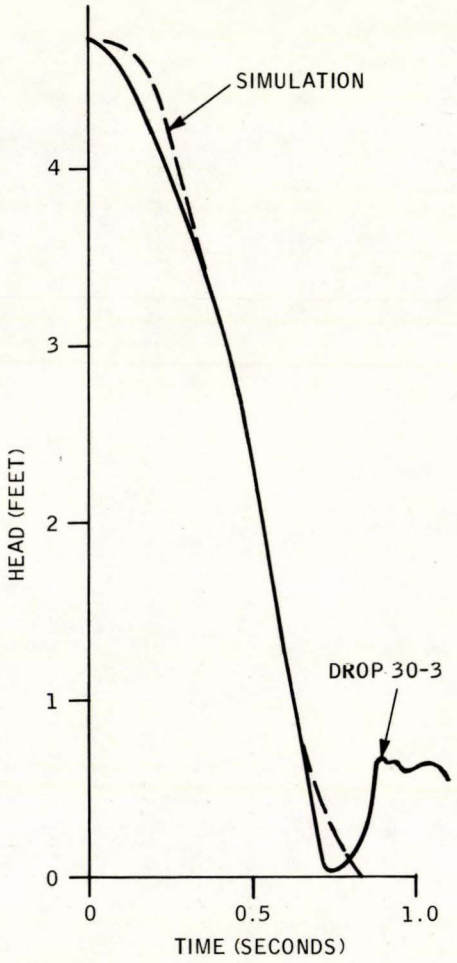

Figure 19. Comparison of Simulated and Actual Flow Based on Fluid Head versus Time for Aero Union B-17 Salvo Drop

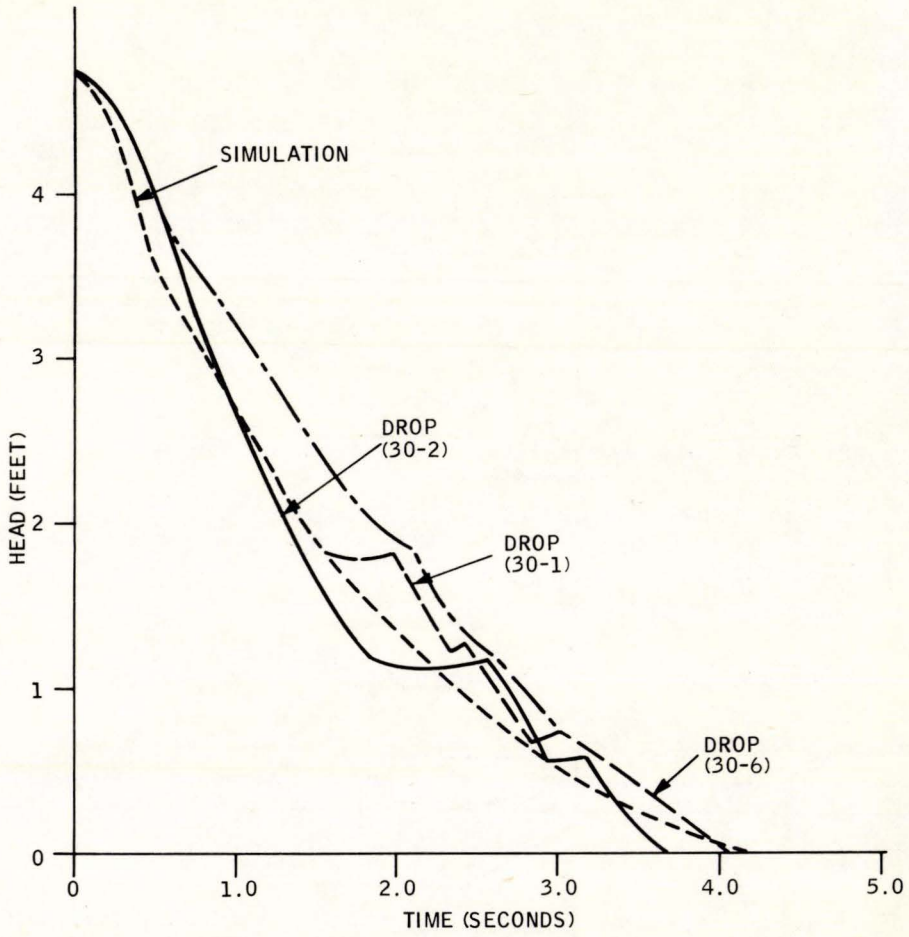

Figure 20. Comparison of Simulated and Actual Flow Based on Fluid Head versus Time for Aero Union B-17 Trail Drop

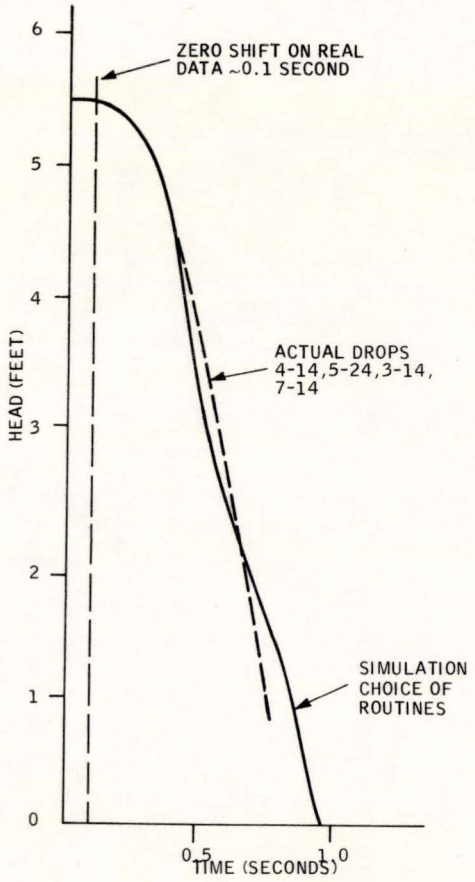

Figure 21. Comparison of Simulated and Actual Flow Based on Fluid Head versus Time for CL-215

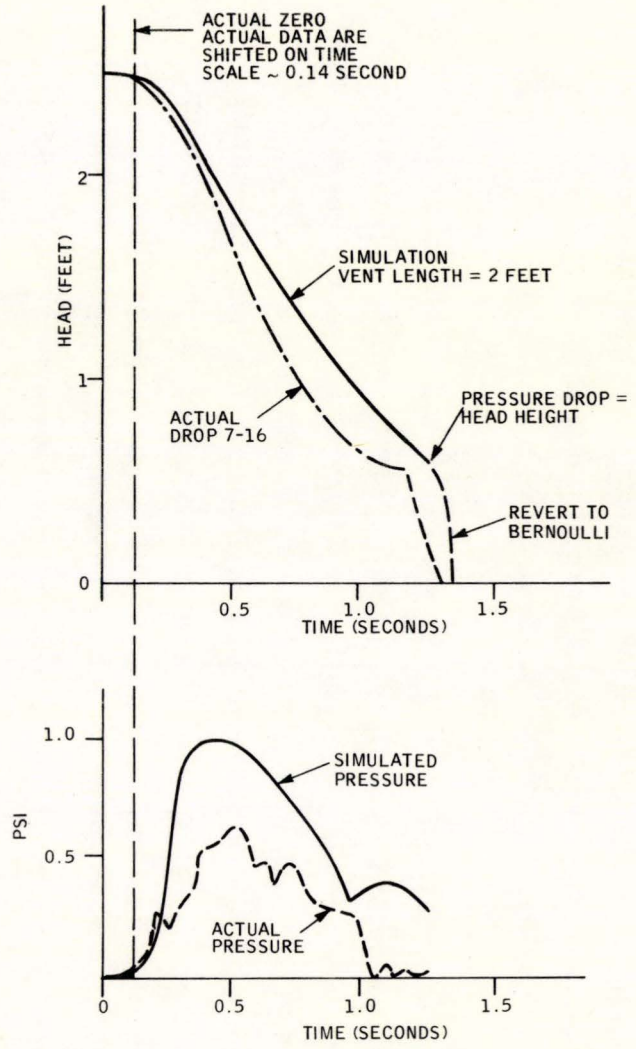

Figure 22. Comparison of Simulated and Actual Flow Based on Fluid Head versus Time for Hemet Valley S2F

In conclusion, the programming technique to correct fundamental problems in the flow rate simulation now produces close approximations to measured data and includes provision to evaluate tank parameters causing negative tank pressures or to recognize conditions for stoppage due to inadequate venting.

The plots of Figures 19 through 22 show the head versus time for oscilloscope data of real drops and those predicted by the revised simulation. It should be noted that an approximate tank geometry description is used in the simulation that would contribute some error to the curve — an error that is amplified in the conversion to flow rate. Furthermore, to compare the form of the evacuation curves rather than their details, simulated curves have been shifted and scaled to the coordinate system of the actuals. The example of S2F tank stoppage was run prior to final refinements of the program, in which oscillations develop around the stopping point. It therefore illustrates the conceptualized method rather than the accepted program. The main difference is in the use of the parameter CAP H, a parameter used by MacPhearson to determine the contribution to velocity of fluid head below the tank in the door volume. This parameter is not used in the updated simulation and should be ignored for a full-open door in any case, even though it appears to damp the oscillation mode.

Simulation as a Rate Predictor

Although the head-versus-time curves are of the most interest in determining the accuracy of the simulation, the objective of the task was to generate flow rates suitable for evaluating tank performances in subsequent steps of the PATSIM program. To obtain flow rates from measured data, the head-versus-time curves are used with a model (to some degree approximate) of tank geometry that in most

cases is similar to the geometry input to PATSIM, or as close an approximation as the input restraints permit. The curve is then differentiated to yield the flow rate used in the simulation. Thus, where the measured head-versus-time curves have an error due to the geometric model, the gallons-versus-time calculated from measured float fall includes a similar geometric error. Consequently, we might expect a closer correspondence in the gallons-versus-time curve than H versus time itself.

Figure 23 shows the gallons versus time for the Aero Union B-17 in terms of the original Bernoulli simulation, the acceleration routine (with pressure) and the free-running routine that chooses between the two flow methods. On this basis, the revised routine appears to predict the flow rate closely. Peak negative pressure predicted in the drop was 0.87 psi corresponding to the measured peak of about 0.85 psi. The tailoff caused by allowing the routine to select the flow mode does not appear to reduce the utility of the simulation, even though the specified acceleration routine appears to produce a closer replica of real data.

Figure 24 shows the pattern cross section of a CL-215 drop with simulated flow rate compared with the actual cross section from drop 4. Although the pattern predicted is not as valid as patterns from hand-input flow rates, it is far better than those derived from the original Bernoulli and should be useful in estimating performance of tanks of the CL-215's complexity.

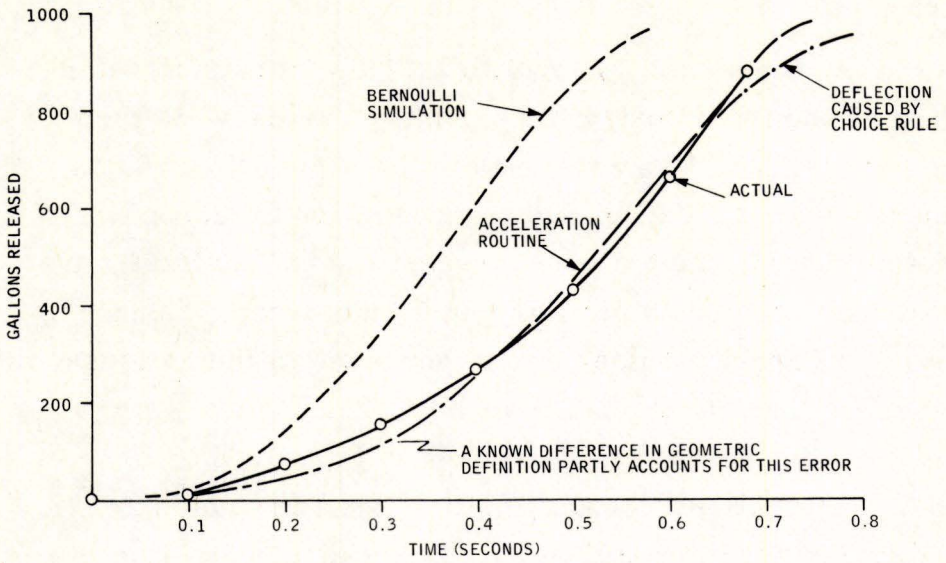

Figure 23. Comparison of Simulated and Actual Evacuation on a Gallons/Time Basis for Aero Union B-17 Salvo Drop

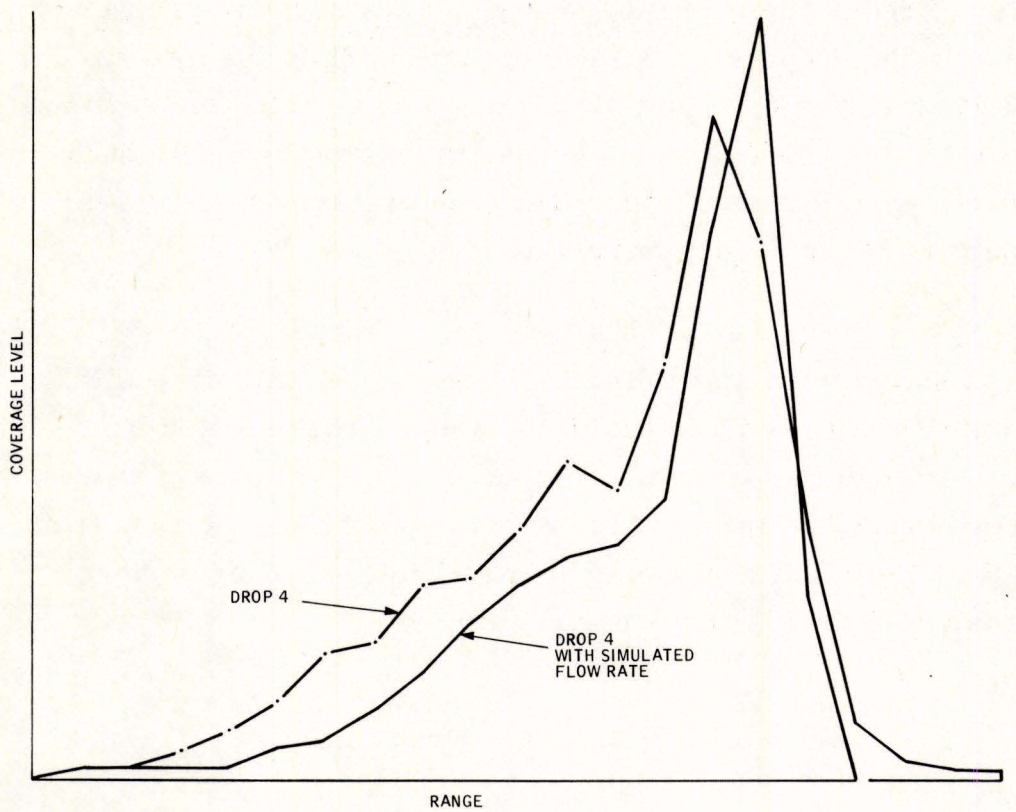

Figure 24. Comparison of Simulated and Actual Pattern Cross Sections for CL-215 Drop 4

SECTION V
DOWNLOADING

The practice of downloading retardant aircraft to meet density altitude load limits causes tank performance to depart from values presently shown in the Airtanker Performance Guides. As a result it is desirable to include a means for estimating or discounting the performance capability within the guides. The Aero Union Corporation's innovation of a standard tank design carrying different load volumes on different aircraft provides both data for evaluating the effect of downloading, and a new importance on prescribing discounting guides within the Performance Guide format. In preparation of Guides for the Aero Union Tank for DC-6 and DC-7 aircraft, Honeywell was contracted to determine rules of thumb for adjusting the guides for an 80% download.

RESULTS AND CONCLUSIONS

Flowrate data were provided by the Forest Service on an Aero Union-tanked DC-6B when fully loaded with 3000 gallons, and downloaded with 2400 gallons (80%). Analysis was conducted to produce independent guide data on the two conditions as a prelude to examining the rules for interpolating between them. It was hoped that a simple rule framework could be identified that would allow the charts and tables for a full load to be adjusted to apply to downloaded conditions. For example, the scheme of Figure 25 shows a nomographic method of estimating downloaded performance from the pattern footprint. In this case the interpolated pattern is based on a shift in altitude to produce equivalent length at Coverage Level 1. The result is an error at the Coverage Level 2 value that is potentially significant. The example illustrates that the variation with respect to

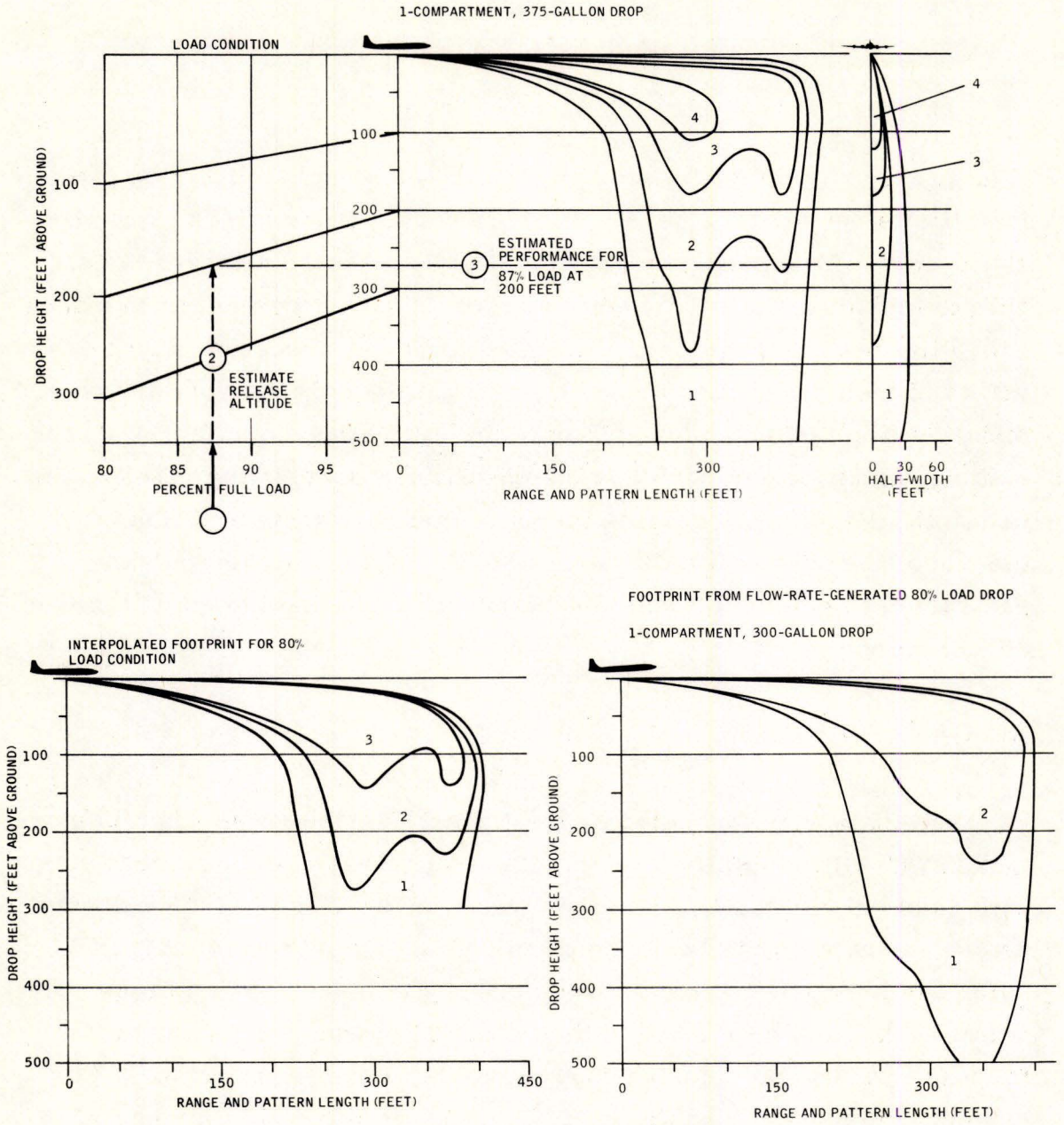

Figure 25. Example of Anticipated Rule of Thumb for Estimating Downloaded Performance

downloading is not monotonic in terms of the basic methodology of guideline development. Similar difficulties arise in developing a consistent set of rules for adjusting other displays in the format. Although a more generalized approach to Performance Guide development could be explored that might allow performance discounting with an acceptable error, pursuit of this alternative was beyond the scope of the immediate effort. It was thus recommended and approved by the Forest Service that separate guidelines be produced at each load condition. Additional investigation of the download problem should be considered after data from the Experimental and Gating System (ETAGS) program became available.

DISCUSSION

In the case of downloading, the total quantity of retardant and its flowrate are both reduced, with a consequent effect on the pattern. The significance of this change depends on the altitude and the desired coverage level. The absolute value of the effect changes with both variables, and consequently represents a third dimension or Z-axis on the guideline charts as they are now formulated (Figure 26). As such it is difficult to display clearly and, even if displayed, difficult to use in estimating performance. Thus, from the standpoint of the data alone, there is little outside of a complex set of nomographs that would allow direct and convenient discounting of the charts presented.

From the standpoint of usage, downloading of significance can be accommodated by several approaches.

Reducing the delivery altitude tends to increase the recovery percentage and reduce the pattern spread. For gum-thickened retardants, a decrease in altitude of 200 feet increases recovery only a little more

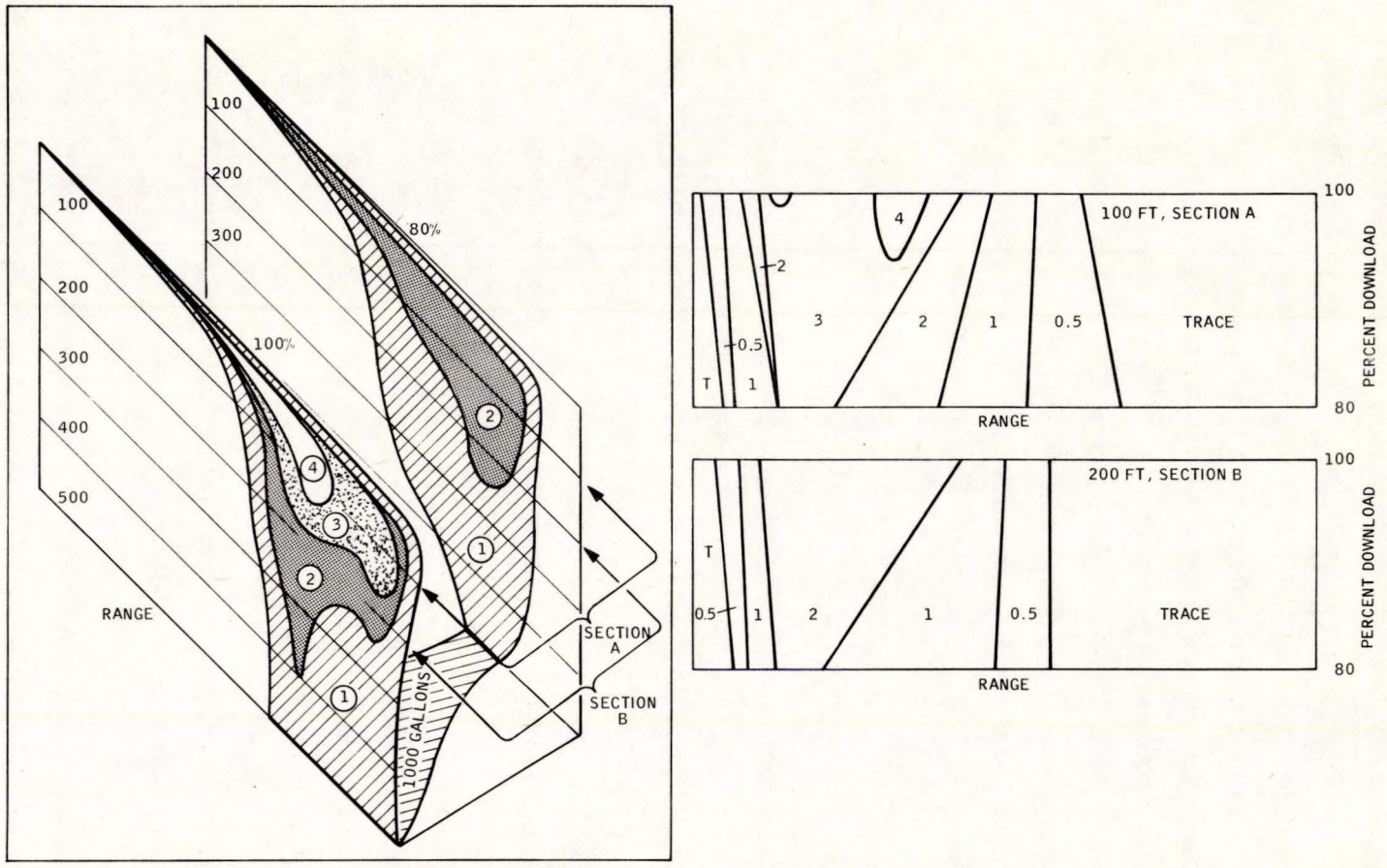

Figure 26. Comparison of Footprints for Downloaded Condition, Single-Compartment Release

than 1%. Although waterlike retardants are more sensitive to recovery, they gain only about 5% through a 200-foot reduction in altitude. Pattern width decreases about 30 feet for each 100 feet of altitude reduction, or about 15%. On this basis, a tank downloaded by 20% with a waterlike retardant would be expected to produce a coverage-length pattern equivalent to a full tank at 100-foot greater drop height (2.5% less recovery plus 15% reduction in pattern density). The rule does produce a fair approximation (Figure 27) but is not sufficiently useful for making clear decisions.

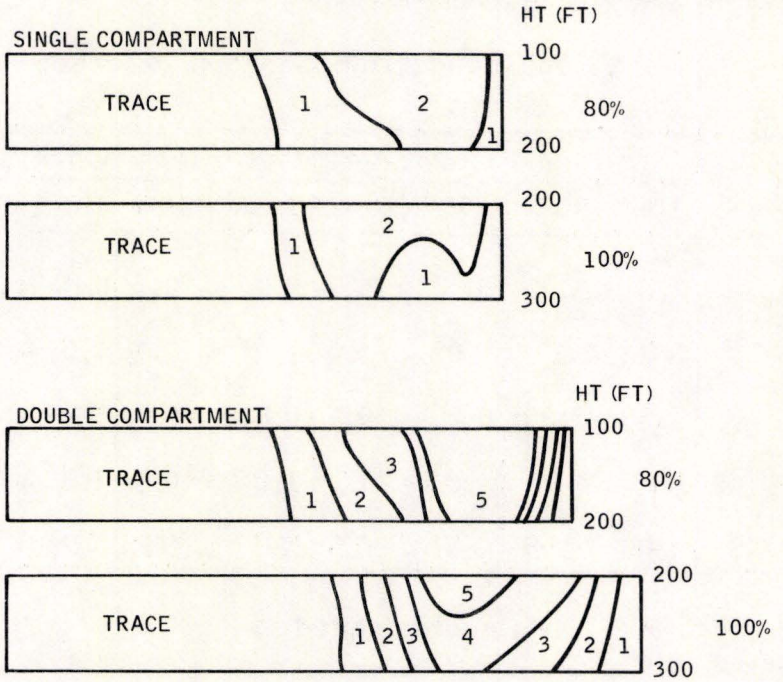

Figure 27. Error Introduced by Discounting Downloaded Performance by Increasing Altitude

A second compensation is to increase the number of tank compartments released — in effect doubling the quantity and flowrate. In this case, the limits to whole-number multipliers introduce greater

errors than the downloading itself — two compartments with 80% load are still 60% greater than a full single-compartment drop.

A third approach is to adjust the time or order of compartment releases to achieve equivalency of performance. Unfortunately, the timing variable itself shows little ordering as shown in Table 1.

Table 1. Timing Variables in Multiple-Compartment Releases

Tank Compartments (T) x No. of Releases (R)	Load Condition / Time Between Releases (Sec)							
	Coverage 1		Coverage 2		Coverage 3		Coverage 4	
	100%	80%	100%	80%	100%	80%	100%	80%
1T X 8R	1.0 →	1.00	0.5 →	0.7	0.8 →	0.5	NR →	NR
2T X 4R	NR →	NR	1.0 →	1.0	1.0 →	0.7	1.0 →	0.5
1T X 4R	1.00 →	1.00	0.5 →	0.7	0.8 →	0.5	NR →	NR
2T X 2R	NR →	NR	1.0 →	1.0	1.0 →	0.7	1.0 →	0.5
1T X 2R	1.00 →	1.00	0.5 →	0.7	NR →	NR	NR →	NR

NR = Not Recommended

Note that the timing increases, decreases, and remains constant throughout the spectrum of conditions. This makes it exceedingly difficult to introduce a scalar correction on the chart decisions in a time sense.

There are also changes in the relative order of tank decisions for best performance in release strategy decisions. These variations also differ radically, depending on the coverage level. The Coverage 1 charts (Figure 28) could legitimately be used without adjustment for download conditions without introducing a significant error. This is not a clear contention in the remaining cases, where the appropriate changes are far more complicated (Figures 29, 30 and 31).

Since a downloading rule of thumb to allow easy adjustment of the Performance Guide data does not appear possible as a simple modification to the existing format, it was recommended that the 2400-gallon and 3400-gallon load conditions for the DC-6B tank be treated as separate guides. This recommendation was subsequently approved by the Forest Service. There does, however, remain a possibility for revision of the basic guide to reflect an adequate set of downloading rules.

The set of approaches for potential exploration involve some departures from the concept of optimized decisions. They involve investigation of the sensitivity of decisions to actual pattern performance and their errors. Essentially, the approach revolves around the basic generation of guide data in a more general (or normative) way. We might assume, for example, that flowrate remained the same for all conditions and that downloading reductions are removed uniformly from the pattern in a manner similar to percent recovery. This would tend to make the downloading spectrum more monotonic and thus more suitable for interpolation. The approach, if practical, requires careful synthesis of the generalized data and confirmation that the error introduced by the recommended strategies is not significant.

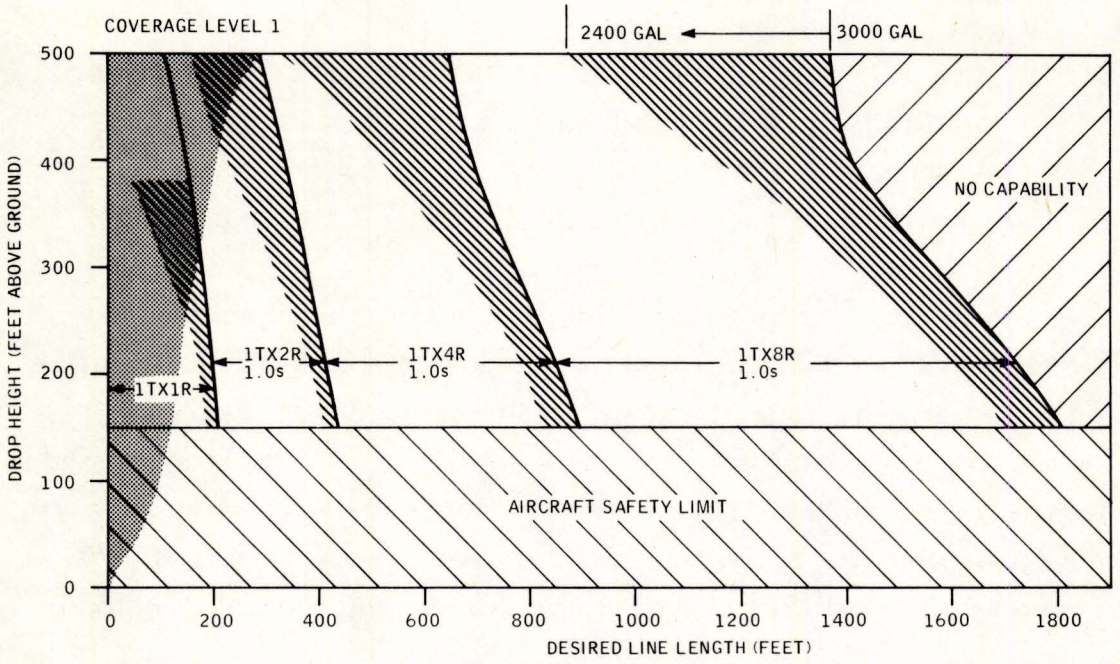

Figure 28. Effect of Downloading on Best Strategy Charts — Water-Like Retardants, Coverage Level 1

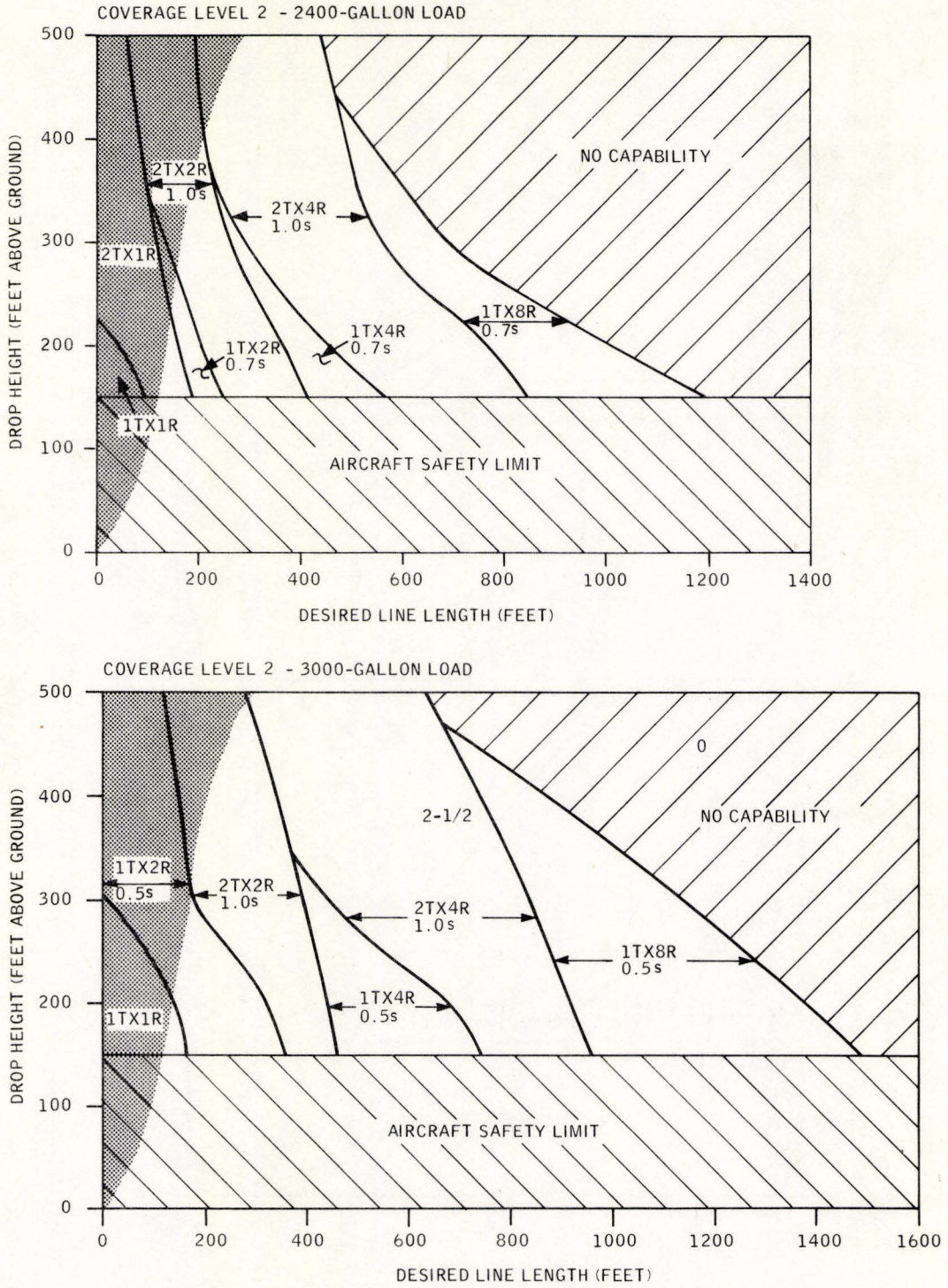

Figure 29. Effect of Downloading on Best Strategy Charts — Water-Like Retardants, Coverage Level 2

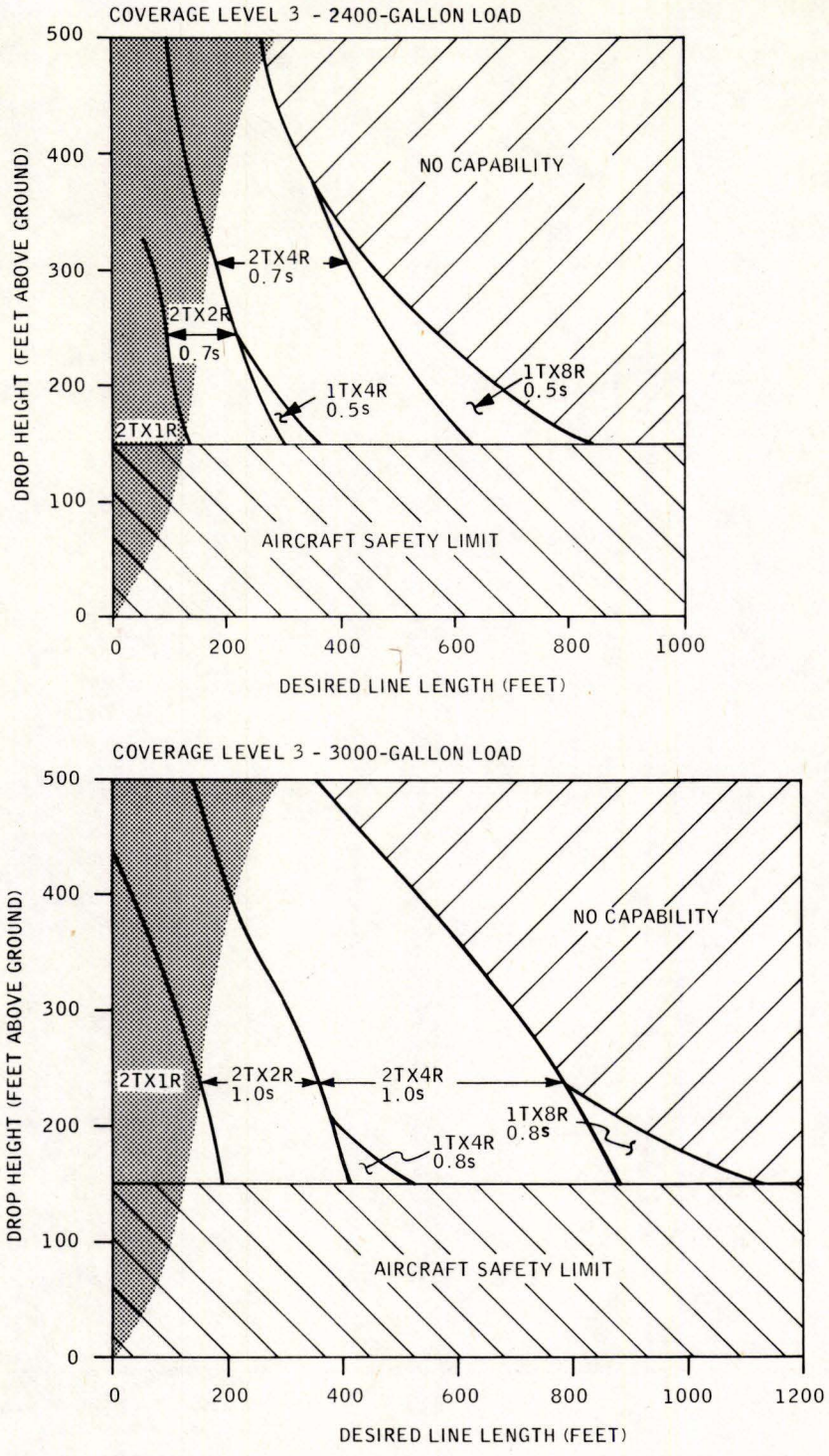

Figure 30. Effect of Downloading on Best Strategy Charts — Water-Like Retardants, Coverage Level 3

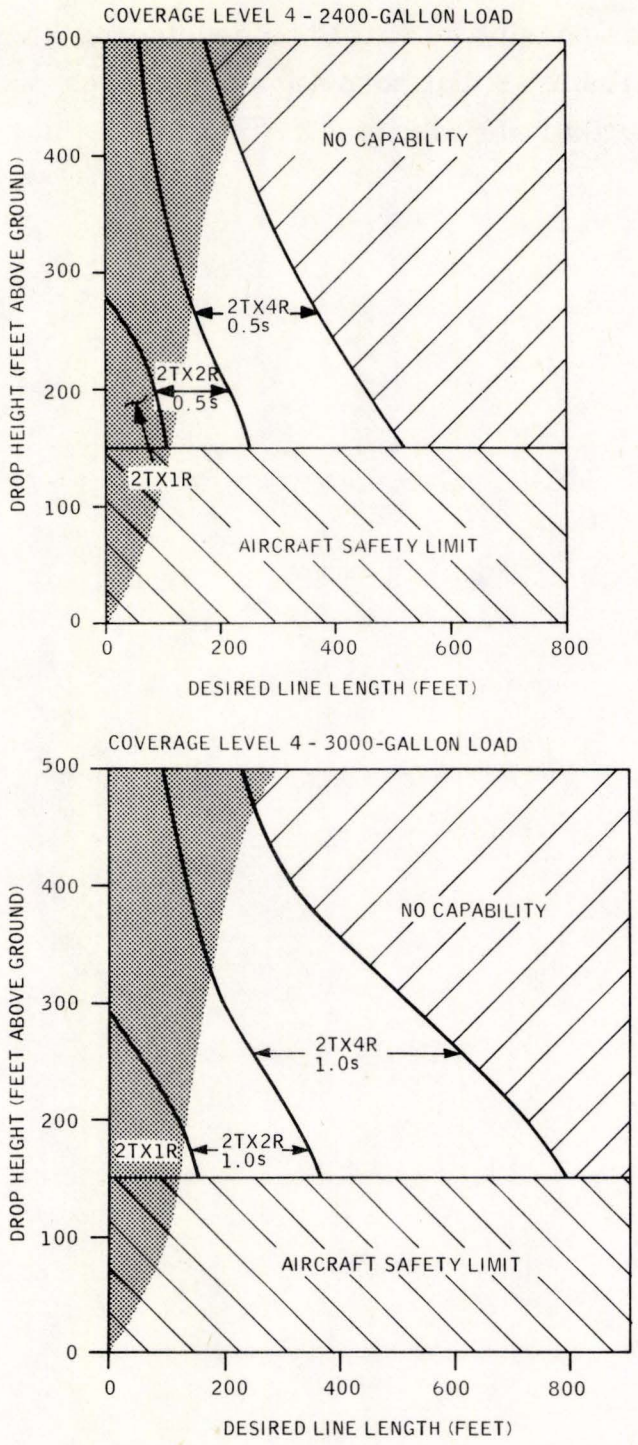

Figure 31. Effect of Downloading on Best Strategy Charts — Water-Like Retardants, Coverage Level 4

The exploration of this possibility should be considered when ETAGS test data become available so that normative hypotheses can be checked against a precise data base.

REFERENCES

1. Swanson, D. H., et al, "Development of User Guidelines for Selected Retardant Aircraft," Final Report, Contract 26-3332, 15 February 1975, Honeywell Inc. (Government and Aeronautical Products Division, Hopkins, Minnesota 55343.

2. Swanson, D. H., and Helvig, T. N., "High-Altitude Retardant Drop Mechanization Study," Final Report, Vol. I, Contract 26-2888, 30 April 1973, Honeywell Inc., Government and Aeronautical Products Division, Hopkins, Minnesota 55343.

3. Swanson, D. H., and Helvig, T. N., "Extended High-Altitude Retardant Drop Mechanization Study, "Final Report, Contract 26-2888, 10 January 1974, Honeywell Inc., Government and Aeronautical Products Division, Hopkins, Minnesota 55343.

4. Eshbach, O. W., and Souders, M. (ed.), "Handbook of Engineering Fundamentals, Third Edition, Sect. 8, Art. 14, John Wiley and Sons, New York.

APPENDIX A

TABULAR RESULTS OF INTERMOUNTAIN B-17 CALIBRATION RUNS

Drop 41 - Fire-Trol 931(LC)

Sheet 1: Simulation and pattern comparison using measured flow rate, measured recovery percent, and simulation rule values for λ, semi-crossrange, and σ (σ = 19 feet).

Sheet 2: Conditions as above, perturbing σ to 17 feet.

Sheet 3: Conditions as above, perturbing σ to 21 feet.

Sheet 4: Conditions as above, using σ = 19 feet, with rule-generated percent recovery.

Drop 29 - Phos-Chek XA

Sheet 5: Simulation and pattern comparison using measured flow rate, measured recovery percent, and simulation rule values (σ = 18 feet).

Sheet 6: Conditions as above, perturbing σ to 16 feet.

Sheet 7: Conditions as above, perturbing σ to 20 feet.

Sheet 8: Conditions as above, using rule-generated σ and percent recovery

Drop 30 - Phos-Chek XA

Sheet 9: Simulation and pattern comparison using measured flow and percent recovery and simulation rule values (σ = 25).

Sheet 10: Conditions as above, perturbing σ to 23 feet.

Sheet 11: Conditions as above, perturbing σ to 27 feet.

RETARDANT TEST-SIMULATION COMPARISON (SHEET 1)

(Water Parameters)

TEST: AIRCRAFT B-17-Int
DROP NO. 41
TANK NO.
ALTITUDE (FEET) 211
SPEED (KNOTS) 136
GALLONS 466
RETARDANT Fire-Trol 931(LC)

SIMULATION: SEMI C-R (FT) 80
λ = .15
σ = 19 (opt)
% RECOVERED 62 (true)
K_1 3.97
K_2 12.0

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	70.6	32.3	33.9	71,550	57,600	25,200
0.3 - 1.0	141.5	104.9	147.9	30,600	21,600	31,050
1.1 - 2.0	67.0	154.8	73.4	5,400	11,700	5,850
2.1 - 3.0	9.7			4.50		
3.1 - 4.0						
4.1 - 5.0						
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	288.8	292.1	255.1	108,000	90,900	62,100

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	.7	1.	.8
AVERAGE (2)	.3	.3	.4

DIFFERENCED DATA: MEAN = -.0430
(TEST-SIMULATED) VARIANCE = .1076

RETARDANT TEST-SIMULATION COMPARISON (SHEET 2)

(Water Parameters)

TEST: AIRCRAFT B-17-Int
DROP NO. 41
TANK NO. _____
ALTITUDE (FEET) 211
SPEED (KNOTS) 136
GALLONS 466
RETARDANT Fire-Trol 931(LC)

SIMULATION: SEMI C-R (FT) 80
λ = .15
σ = 17
% RECOVERED 62 (true)
K_1 3.97
K_2 12.0

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) = _____
A(1) = _____
A(0) = _____

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	70.6	32.6	33.9	71,550	45,900	25,200
0.3 - 1.0	141.5	110.8	147.9	30,600	21,600	31,050
1.1 - 2.0	67.0	148.7	73.4	5,400	9,900	5,850
2.1 - 3.0	9.7			450		
3.1 - 4.0						
4.1 - 5.0						
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	288.8	292.1	255.1	108,000	77,400	62,100

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	.7	1.0	.8
AVERAGE (2)	.3	.4	.4

DIFFERENCED DATA: MEAN = -.0478
(TEST-SIMULATED) VARIANCE = .4131

RETARDANT TEST-SIMULATION COMPARISON (SHEET 3)

(Water Parameters)

TEST: AIRCRAFT B-17-Int
DROP NO. 41
TANK NO.
ALTITUDE (FEET) 211
SPEED (KNOTS) 136
GALLONS 466
RETARDANT Fire-Trol 931(LC)

SIMULATION: SEMI C-R (FT) 80
λ = .15
σ = 21
% RECOVERED 62 (true)
K_1 3.97
K_2 12.0

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	70.6	33.5	33.9	71,550	56,700	25,200
0.3 - 1.0	141.5	147.9	147.9	30,600	24,300	31,050
1.1 - 2.0	67.0	73.9	73.4	5,400	9,900	5,850
2.1 - 3.0	9.7			450		
3.1 - 4.0						
4.1 - 5.0						
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	288.8	255.4	255.1	108,000	90,900	62,100

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	.7	.8	.8
AVERAGE (2)	.3	.4	.4

DIFFERENCED DATA: MEAN = -.0430
(TEST-SIMULATED) VARIANCE = .0921

RETARDANT TEST-SIMULATION COMPARISON (SHEET 4)

(Water Parameters)

TEST: AIRCRAFT B-17-Int
DROP NO. 41
TANK NO.
ALTITUDE (FEET) 211
SPEED (KNOTS) 136
GALLONS 466
RETARDANT Fire-Trol 931(LC)

SIMULATION: SEMI C-R (FT) 80
λ = .15
σ = 19 (opt)
% RECOVERED 69.9 (rule)
K_1 3.97
K_2 12.0

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	70.6	34.5	33.9	71,550	56,700	25,200
0.3 - 1.0	141.5	110.7	147.9	30,600	21,600	31,050
1.1 - 2.0	67.0	184.2	73.4	5,400	12,600	5,850
2.1 - 3.0	9.7			450		
3.1 - 4.0						
4.1 - 5.0						
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	288.8		255.1	108,000	90,900	62,100

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	.7	1.1	.8
AVERAGE (2)	.3	.4	.4

DIFFERENCED DATA: MEAN = -.0824
(TEST-SIMULATED) VARIANCE = .1335

RETARDANT TEST-SIMULATION COMPARISON (SHEET 5)

TEST: AIRCRAFT B-17-Int
DROP NO. 29
TANK NO.
ALTITUDE (FEET) 194
SPEED (KNOTS) 124
GALLONS 466
RETARDANT Phos-Check XA

SIMULATION: SEMI C-R (FT) 75
λ = .15
σ = 18
% RECOVERED 88.6
K_1 3.97
K_2 12.

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	46.7	36.0	17.9	50,400	38,700	13,050
0.3 - 1.0	125.0	71.2	125.0	24,750	15,300	24,750
1.1 - 2.0	91.3	134.6	86.1	6,300	9,900	5,850
2.1 - 3.0	98.2	174.2	101.4	4,500	7,200	4,500
3.1 - 4.0	32.6		49.4	900		1,350
4.1 - 5.0	19.1		19.1	450		450
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	412.9	416.0	398.9	87,300	71,100	49,950

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	1.6	1.6	1.8
AVERAGE (2)	.5	.6	.8

DIFFERENCED DATA: MEAN = -.0418
(TEST-SIMULATED) VARIANCE = .2177

RETARDANT TEST-SIMULATION COMPARISON (SHEET 6)

TEST: AIRCRAFT B-17-Int
DROP NO. 29
TANK NO.
ALTITUDE (FEET) 194
SPEED (KNOTS) 124
GALLONS 466
RETARDANT Phos-Chek XA

SIMULATION: SEMI C-R (FT) 75
λ = .15
σ = 16
% RECOVERED 88.6
K_1 3.97
K_2

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	46.7	34.7	17.9	50,400	39,600	13,050
0.3 - 1.0	125.0	59.1	125.0	24,750	14,400	24,750
1.1 - 2.0	91.3	132.2	86.1	6,300	9,900	5,850
2.1 - 3.0	98.2	135.4	101.4	4,500	5,400	4,500
3.1 - 4.0	32.6	54.5	49.4	900	1,800	1,350
4.1 - 5.0	19.1		19.1	450		450
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	412.9	416.0	398.9	87,300	71,100	49,950

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	1.6	1.8	1.8
AVERAGE (2)	.5	.6	.8

DIFFERENCED DATA: MEAN = -.0418
(TEST-SIMULATED) VARIANCE = .2434

RETARDANT TEST-SIMULATION COMPARISON (SHEET 7)

TEST: AIRCRAFT B-17-Int
DROP NO. 29
TANK NO. ---
ALTITUDE (FEET) 194
SPEED (KNOTS) 124
GALLONS 466
RETARDANT Phos-Chek XA

SIMULATION: SEMI C-R (FT) 75
λ = .15
σ = 20
% RECOVERED 88.6
K_1 3.97
K_2 12.

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	46.7	40.5	17.9	50,400	51,300	13,050
0.3 - 1.0	125.0	79.9	125.0	24,750	15,300	24,750
1.1 - 2.0	91.3	169.7	86.1	6,300	11,700	5,850
2.1 - 3.0	98.2	125.9	101.4	4,500	5,400	4,500
3.1 - 4.0	32.6		49.4	900		1,350
4.1 - 5.0	19.1		19.1	450		450
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	412.9	416.0	398.9	87,300	83,700	49,950

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	1.6	1.5	1.8
AVERAGE (2)	.5	.5	.8

DIFFERENCED DATA: MEAN = -.0359
(TEST-SIMULATED) VARIANCE = .1779

RETARDANT TEST-SIMULATION COMPARISON (SHEET 8)

TEST: AIRCRAFT B-17-Int
DROP NO. 29
TANK NO.
ALTITUDE (FEET) 194
SPEED (KNOTS) 124
GALLONS 466
RETARDANT Phos-Chek XA

SIMULATION: SEMI C-R (FT) 75
λ = .15
σ = 18
% RECOVERED 75.6 (rule value)
K_1 3.97
K_2 12.

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	46.7	32.5	17.9	50,400	39,600	13,050
0.3 - 1.0	125.0	84.3	125.0	24,750	17,100	24,750
1.1 - 2.0	91.3	156.2	86.1	6,300	10,800	5,850
2.1 - 3.0	98.2	82.0	101.4	4,500	3,600	4,500
3.1 - 4.0	32.6		49.4	900		1,350
4.1 - 5.0	19.1		19.1	450		450
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	412.9	354.97	398.9	87,300	71,100	49,950

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	1.6	1.4	1.8
AVERAGE (2)	.5	.5	.8

DIFFERENCED DATA: MEAN = .0384
(TEST-SIMULATED) VARIANCE = .1990

RETARDANT TEST-SIMULATION COMPARISON (SHEET 9)

TEST: AIRCRAFT B-17-Int
DROP NO. 30
TANK NO.
ALTITUDE (FEET) 393
SPEED (KNOTS) 126
GALLONS 466
RETARDANT Phos-Chek XA

SIMULATION: SEMI C-R (FT) 100
λ = .15
σ = 25
% RECOVERED 76.1
K_1 3.97
K_2 12.

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	91.9	37.7	24.6	92,700	58,500	18,000
0.3 - 1.0	108.9	112.7	107.9	23,400	24,300	22,950
1.1 - 2.0	123.3	206.6	133.8	8,550	15,300	9,000
2.1 - 3.0	30.5		31.8	1,350		1,350
3.1 - 4.0						
4.1 - 5.0						
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	354.64	356.96	298.1	126,000	98,100	51,300

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	.9	1.1	1.2
AVERAGE (2)	.3	.4	.6

DIFFERENCED DATA: MEAN = -.0667
(TEST-SIMULATED) VARIANCE = .1047

RETARDANT TEST-SIMULATION COMPARISON (SHEET 10)

TEST: AIRCRAFT B-17-Int
DROP NO. 30
TANK NO.
ALTITUDE (FEET) 393
SPEED (KNOTS) 126
GALLONS 466
RETARDANT Phos-Chek XA

SIMULATION: SEMI C-R (FT) 100
λ = .15
σ = 23
% RECOVERED 76.1
K_1 3.97
K_2 12.

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	91.9	43.1	24.6	92,700	63,000	18,000
0.3 - 1.0	108.9	96.7	107.9	23,400	19,800	22,950
1.1 - 2.0	123.3	217.1	133.8	8,550	15,300	9,000
2.1 - 3.0	30.5		31.8	1,350		1,350
3.1 - 4.0						
4.1 - 5.0						
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	354.64	356.96	298.1	126,000	98,100	51,300

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	.9	1.1	1.2
AVERAGE (2)	.3	.4	.6

DIFFERENCED DATA: MEAN = -.0667
(TEST-SIMULATED) VARIANCE = .1114

RETARDANT TEST-SIMULATION COMPARISON (SHEET 11)

TEST: AIRCRAFT B-17-Int
DROP NO. 30
TANK NO.
ALTITUDE (FEET) 393
SPEED (KNOTS) 126
GALLONS 466
RETARDANT Phos-Chek XA

SIMULATION: SEMI C-R (FT) 100
λ = .15
σ = 27
% RECOVERED 76.1
K_1 3.97
K_2 12.

DOOR OPENING RATE COEFFICIENTS:
A(3) = Actual flow rate used
A(2) =
A(1) =
A(0) =

INTERVAL (GALLONS/ 100 FT^2)	GALLONS			AREA (FT^2)		
	TEST	SIMULATION	SMOOTHED TEST	TEST	SIMULATION	SMOOTHED TEST
0 - 0.2	91.9	39.2	24.6	92,700	70,200	18,000
0.3 - 1.0	108.9	129.9	107.9	23,400	26,100	22,950
1.1 - 2.0	123.3	187.8	133.8	8,550	14,400	9,000
2.1 - 3.0	30.5		31.8	1,350		1,350
3.1 - 4.0						
4.1 - 5.0						
5.1 - 6.0						
6.1 - 7.0						
7.1 - 8.0						
8.1 - 9.0						
9.1 - 10.						
>10						
TOTAL	354.64	356.96	298.1	126,000	110,700	51,300

	TEST DATA	SIMULATION DATA	SMOOTHED TEST DATA
AVERAGE (1)	.9	1.0	1.2
AVERAGE (2)	.3	.3	.6

DIFFERENCED DATA: MEAN = -.0598
(TEST-SIMULATED) VARIANCE = .0910

APPENDIX B
PATSIM PROGRAM

PATSIM is a retardant ground pattern simulation program. The input and output were designed for ease of use. A small deck of input cards provide data on measured tank flow rate, and these cards need not be changed from run to run. The remaining variable input consists of delivery speed, drop height, retardant type and number of compartments employed. The output consists of a graphic pattern representation, retardant contour quantities (gallons) and areas, and pattern-length data. An optional subroutine PATADD will also print out maximum line and the appropriate delay between releases for sequential compartment releases.

PROGRAM OPERATIONAL METHODS

The program has eight basic operation methods, allowing a wide selection of the input descriptors of the tank to be simulated (Table B1). These include three modes where the tank is described geometrically, and flow rate is calculated from door opening rate using either (1) the original Bernouli equations for steady-state flow, (2) an acceleration rule descriptive of most tanks, or (3) an algorithm selecting between Bernoulli or acceleration routines due to tank geometry. For each technique the option is provided to include the tank system's vent geometry, to estimate flow-induced pressures and their effect on the predicted flow-rate.

The remaining run options, 4 through 7, enable the use of directly measured flow data — total gallons released after each of a series of time increments. Experience has shown that door-opening rate data and ejection velocity data can be ignored with little effect on the

accuracy of the prediction, therefore run mode 8 is recommended for most applications. It is also the mode requiring the least number of inputs.

Table B1. PATSIM Program Run Options

With Predictive Flow-Rate	1. Theoretical, tank flow-rate, constant door opening rate (requires tank geometry input) 2. Theoretical tank flow-rate, variable (polynominal) door rate (requires tank geometry input) 3. Theoretical tank flow-rate with tabular (experimental) door rule (requires tank geometry input)
From Experimental Flow-Rate Data	4. Experimental tank flow data, quantity and door angle versus time (variable ejection velocity is used) 5. Experimental tank flow data, quantity versus time, constant door opening rate (variable ejection velocity used) 6. Experimental tank flow data, quantity versus time, variable (polynominal) door-opening angle (variable ejection velocity used) 7. Experimental tank flow data, quantity versus time, constant ejection velocity 8. Experimental tank flow data, quantity versus time, no door angle or ejection velocity input (program defaults to 16-fps ejection velocity)

One output option enables selection of the PATADD subroutine that calculates maximum line length and tank delay sequences for overlapping patterns in generating line.

PROGRAM INPUT

All input variables and constants are stored in an A-array. The variable numbers and constant names are equivalenced to locations in this array. The array location numbers are used when preparing input.

The format on an input card is:

Col. 1-30 :	1st variable number	Col. 11-20 :	1st variable number
21-30 :	2nd variable number	31-40 :	2nd variable number
41-50 :	3rd variable number	51-60 :	3rd variable number
61-70 :	4th variable number	71-80 :	4th variable number

All numbers are punched with decimal points and may be located anywhere in the field.

From one to four variables or constants may be entered on one input card. A completely blank card signals the end of one set of data or run. The variables need not be entered in any particular numerical order.

Another type of input card is used for comments or identifying titles. This card begins with an asterisk (*) in Column 1. Columns 2 through 80 of this card may be punched with alphanumeric information. This card is printed in the listing of input data given in the program. Comment cards may be entered anywhere in the input deck.

A typical input deck for operating from measured flow data is shown in Figure B1. Table B2 describes the input requirements

for all seven operating modes. Definitions and dimensions of all input variables and constants can be found in the program glossary (Table B3). Aircraft tank descriptors are given in Figure B2.

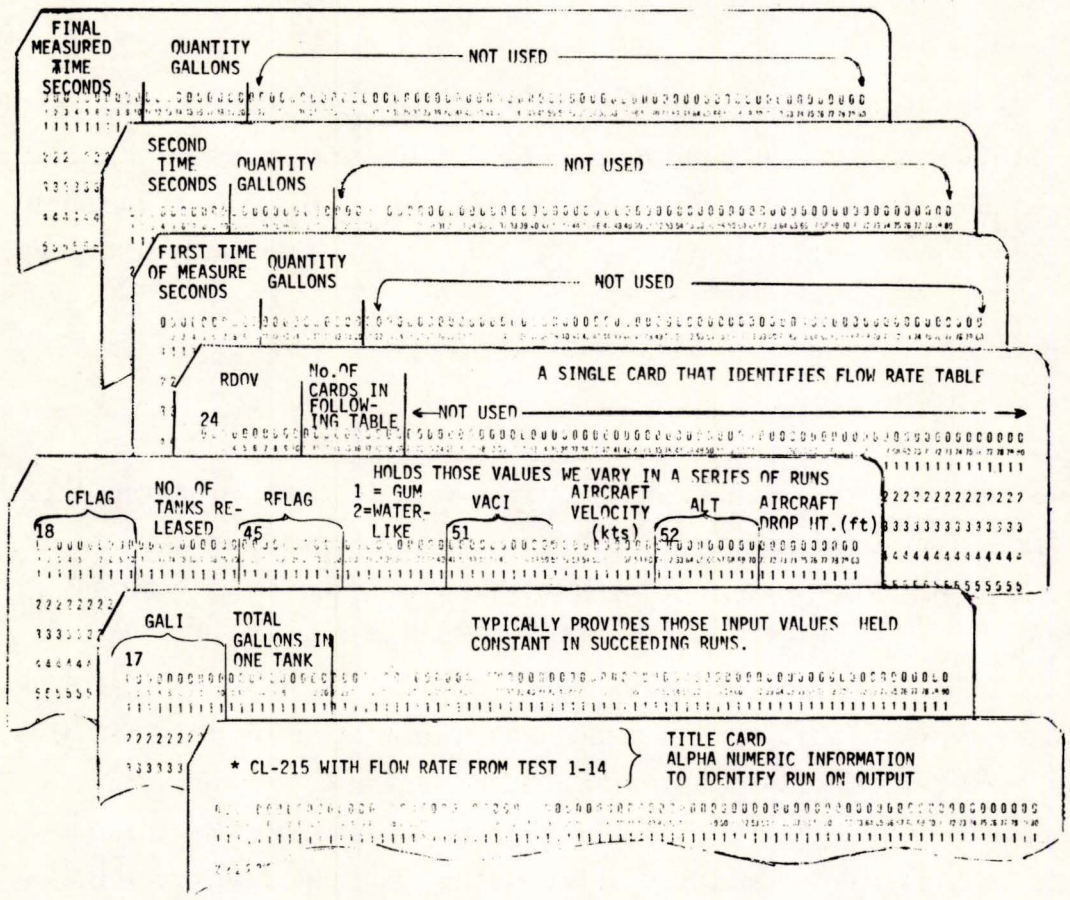

Figure B1. Typical Input Deck

Table B2. Program Input for the Different Program Operation Methods

Variable Number	Variable Name	Program Operation Methods: To Predict Flow Rate 1	2	3	From Measured Flow Rate 4	5	6	7	8
1	ACFLAG	R	R	R					
2	ELT	R	R	R					
3	ELE	R	R	R	R	R	R		NO
4	B	R	R	R	R	R	R		NO
5	H	R	R	R					
6	CAPH	R	R	R					
7	HI	R	R	R					
8	WT	R	R	R					
9	SW0	R	R	R					
10	SW1	R	R	R					
11	SW2	R	R	R					
12	SW3	R	R	R					
13	PSII	R	R	R					
14	PHIO	R	R						
15	THMAXI	R	R	R		R	R		
16	THEP	R				R			
17	GALI	R	R	R	R	R	R	R	R
18	CFLAG	R	R	R	R	R	R	R	R
19	TMAX	NO	R	NO	NO	NO	R	NO	
20	COEF(1)		R				R		
21	COEF(2)		R				R		
22	COEF(3)		R				R		
23	COEF(4)		R				R		
24	RDQV*	NO	NO	NO	R	R	R	R	R
25	CONVEX	NO	NO	NO	NO	NO	NO	R	NO
26	FLVENT	P	P	P					
27	AVENT	P	P	P					
28	DVENT	P	P	P					
29	PNVENT	P	P	P					
30	TTAB*	NO	NO	R					
45	RFLAG	R	R	R	R	R	R	R	R
46	FNPAT	} Optional - use for pattern overlaps only							
47	FNRAN								
48	FNCRAN								
51	VACI	R	R	R	R	R	R	R	R
52	ALT	R	R	R	R	R	R	R	R
55		**	**	**					
56		P	P	P					

* Tabular Input Required — following the variable.

** Required to select a flow rate algorithm other than the original Bernoulli, 1 = choice of routines, 2 = acceleration (free-fall) only

R Means input is required, blank means not required (but will not interfere with program operation) and NO means must not be used or program will not work properly.

P Means required when the pressure buildup due to venting is required in the simulation optional.

Table B3. PATSIM Program Glossary (1 of 6)

Aircraft Tank Variables

Number (1)	Name	Description	Initial Value (2)	Units
1	ACFLAG	ACFLAG = 2., program uses CL-215 tank coding ≠2., program uses coding for remaining tanks	0	-
2	ELT	Tank length	0	ft
3	ELE	Door opening length	0	ft
4	B	Door width	0	ft
5	H	Vertical measurement between door hinge and tank discontinuity.	0	ft
6	CAPH	Initial head height when tank is full	0	ft
7	HI	Height of first tank section	0	ft
8	WT	Width of top of liquid when tank is full	0	ft
9	SWO	Slope of tank sides	0	-
10	SW1	" " "	0	-
11	SW2	" " "	0	-

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table B3. PATSIM Program Glossary (2 of 6)

Aircraft Tank Variables

Number (1)	Name	Description	Initial Value(2)	Units
12	SW3	Slope of tank sides	0	-
13	PSII	Angle of tank bottom with horizontal	0	degrees
14	PHIO	Tank discharge angle measured from horizontal	0	"
15	THMAXI	Maximum door angle from horizontal	0	"
16	THEP	Door opening rate (if uniform rate is used)	0	rad/sec
17	GALI	Total number of gallons in a tank	0	gallons
18	CFLAG	Number of tanks released	1.	-
19	TMAX	Door opening time if polynomial is used. For uniform rate enter THEP value and make TMAX=O	0	sec
20	$\bar{C}OEF(1)$	Coefficient of t^3 in door opening angle polynomial	0	-
21	$\bar{C}OEF(2)$	" " t^2 " " " "	0	-
22	$\bar{C}OEF(3)$	" " t " " " "	0	-

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table B3. PATSIM Program Glossary (3 of 6)

Aircraft Tank Variables

Number (1)	Name	Description	Initial Value(2)	Units
23	COEF(4)	Constant term in door opening angle polynomial	0	-
24	RDQV	Flag to select the option for input Q vs T. Also the number of entries in this table. (See table description)	0	-
25	CONVEX	Constant exit velocity if this option is wanted. Otherwise use CONVEX=0	0	ft/sec
26	FLVENT	Length of tank vent	0	ft
27	AVENT	Area of combined vents	0	ft^2
28	DVENT	Diameter of vent	0	ft
29	FNVENT	Number of vents	0	
30	TTAB	Flag selects option to use tabular door angle versus time if set		

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table B3. PATSIM Program Glossary (4 of 6)

Constants

Number (1)	Name	Description	Initial Value(2)	Units
31	AFLAG	AFLAG = 1., print ejection data = 0., do not print ejection data	0	-
32	BFLAG	BFLAG = 1., print bulk increment data = 0., do notprint bulk increment data	0	-
33	DFLAG	A print control - tells how many print lines to leave out	9.	-
34	EFLAG	Reduced memory flag. EFLAG = 1., reduced memory run (CM120000) EFLAG = 0., large memory run(CM300000)	1.	-
35	GFLAG	Not used	2	-
36	HFLAG	Not used	1.	-
37	ALF	Area reduction factor	.85	-
38	PP	Pressure	0.	lb/ft^2
39	RHOI	Density of liquid	66.724	$slugs/ft^3$
40	K1	Erosion factor	3.97	-
41	K2	Erosion factor	12.	-

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table B3. PATSIM Program Glossary (5 of 6)

Constants

Number (1)	Name	Description	Initial Value(2)	Units
42	DELT	Integration time interval	.002	sec
43	TR	Number of time intervals for bulk liquid breakdown	10.	-
44	TX	Size of time interval for bulk breakdown	.02	sec

(1) The number is also the location in the A-array
(2) Initial value is set by the program

Table B3. PATSIM Program Glossary (6 of 6)

Drop Delivery Variables

Number (1)	Name	Description	Initial Value(2)	Units
51	VACI	Aircraft speed	0.	knots
52	ALT	Aircraft altitude	0.	ft
45	RFLAG	Retardant type flag. RFLAG = 1. means PHOS-CHEK; RFLAG = 2. means water and water-like retardants	1.	-
46	FNPAT	Number of overlapping patterns for multiple tank drops Use FNPAT = 1. or 0. for single tank drops.	0.	-
47	FNRAN	Displacement in range between pattern centers for multiple tank drops - number of cells(one cell = 30 ft)	0.	-
48	FNCRAN	Displacement in crossrange between pattern centers for multiple tank drops-number of cells(one cell = 15 ft)	0	-
18	CFLAG	Number of tanks released simultaneously. A multiplier of flow rate.	1.	-
53	ADD	Pattern Length for multiple patterns flag. If ADD > 0 means pattern lengths and time intervals are computed. If ADD $\leq$ 0 pattern lengths and time intervals are not computed. See Note	0.	-
54		A Flag to stop the run after flow value is determined. 0 = continue through pattern simulation, 1 = stop.	0.	
55		A Flag to select flow rate model: 0 = Bernoulli 2 = Acceleration only, 1 = choice of routines	0.	
56		A Flag to select pressure routine (= 1) or conduct the computation ignoring pressure (= 0).	0.	

(1) The number is also the location in the A-array
(2) Initial value is set by the program

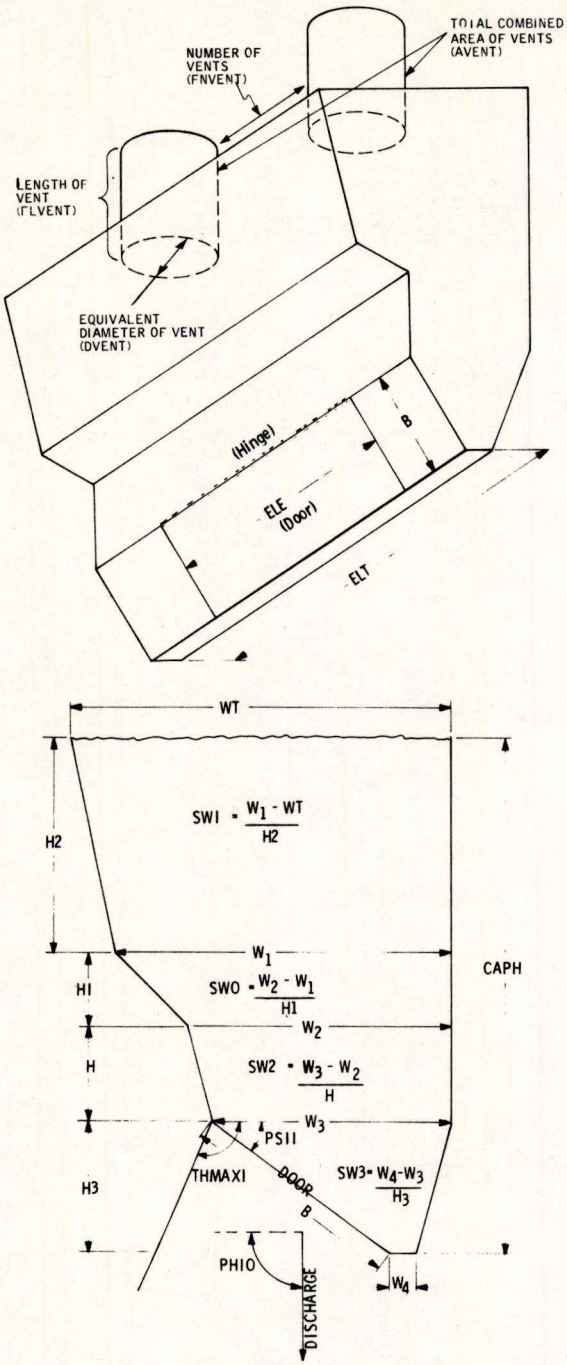

Figure B2. Aircraft Tank Descriptors

SPECIAL INSTRUCTIONS ON THE USE OF MEASURED DATA

Q versus T Table Format for Input Flow Data

When this option is used the RDQV variable must be on one card and the Q-versus-T table must immediately follow this card. There is one table entry per card as follows:

	Column 1-10	-	Time (seconds)
	Column 11-20	-	Q, retardant quantity (gallons)
Optional	Column 21-30	-	TMPS, door opening angle (degrees) If TMPS values are entered as zero, the original program options are used, i.e., constant door opening rate or cubic equation fit to test data.

The number of cards in this table is equal to the number following the RDQV variable number.

The time step size used in the input flow data may differ from the time step size used within the program. The program uses a relatively small time step size of 0.02 sec , whereas the input flow data step size may be larger (0.1 sec for example). In this case the program will interpolate between time steps to provide data every 0.02 second. The interpolation for flow quantity is linear. The door opening angle used between input time points within the program is the average value for the larger input interval. The program will also extrapolate the flow quantity data based on the last two points in the input data. This extrapolation is extended linearly to the retardant quantity entered in the variable named GALI. This interpolation and extrapolation is

automatically done by the program whenever the variable RDQV is entered as a positive number. The program can be forced to use the data in its input form (without interpolation or extrapolation) by entertaining the variable RDQV as a negative number.

Door Angle Versus Time Table

To employ this routine, the TTAB variable must be on one card specifying the number of cards (table entries) that follow. There is one table entry per card in the following format:

Columns 1 - 10 : Time (seconds)
Columns 11 - 20 : TMPS, door-opening angle (degrees)

The variables PSI 1 and THMAX 1 must be entered when using this option. They are related as follows:

THETA = TMPS + PSII where the maximum value of THETA = THMAXI.

Pattern Length and Time Interval Option (ADD Option)

If this option is used another input card must follow the variable number 53 card. This card contains a code in columns 1 to 8 that indicates the number of patterns to be added together. A "1" in a column means to add the column number of patterns. For example, "1101001" would compute one-, two-, four-, and eight- compartment drops.

PROGRAM OUTPUT

The output of the program, consists of the following:

- The input data
- A detailed pattern plot (Figure B3)
- Contour interval summaries (Figure B4)
- A scaled pattern plot (Figure B-5)
- Pattern length data (Figure B4)
- The PATADD output, if used. (Figure B6)

.0	.0	.0	.2	.2	.2	.2	.0	.0	.0
.0	0.0	.2	.2	.2	.2	.2	.2	0.0	0.0
.0	0.0	.2	.2	.2	.2	.2	.2	0.0	0.0
.0	.2	.2	.2	.2	.2	.2	.2	.2	0.0
.0	.2	.2	.2	.3	.3	.2	.2	.2	.0
.2	.2	.2	.3	.3	.3	.3	.2	.2	.2
.2	.2	.2	.4	.6	.6	.4	.2	.2	.2
.2	.2	.3	.6	.9	.9	.6	.3	.2	.2
.2	.2	.4	.8	1.2	1.2	.8	.4	.2	.2
.2	.2	.5	1,1	1.7	1.7	1.1	.5	.2	.2
.2	.3	.6	1.4	2.3	2.3	1.4	.6	.3	.2
.2	.3	.7	1.7	2.8	2.8	1.7	.7	.3	.2
.2	.3	.9	2.2	3.6	3.6	2.2	.9	.3	.2
.0	.3	.9	2.4	4.0	4.0	2.4	.9	.3	.0
.0	.3	1.0	2.6	4.4	4.4	2.6	1.0	.3	.0
.0	.2	1.0	2.6	4.4	4.4	2.6	1.0	.2	.0
.0	.1	.6	1.6	2.5	2.5	1.6	.6	.1	.0
.0	0.0	0.0	.2	.2	.2	.2	0.0	0.0	0.0

Figure B3. Detailed Pattern Data in "Computer Scale"

CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION
(GALLONS/100 SQUARE FEET)
TOTAL WITHIN EACH INTERVAL

0.0-0.2	0.3-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0
48.4064	110.9556	116.5968	136.3993	60.5805	115.2700	0.0000	0.0000	0.0000

8.1-9.0	9.1-10
0.0000	0.0000

> 10
0.0000

TOTAL AMOUNT OF RETARDANT ON GRID = 588.21 GALLONS PERCENT OF TOTAL= 84.030
AVERAGE PATTERN LEVEL IS 2.2 GALLONS PER 100 SQUARE FEET

CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION
(SQUARE-FOOT COVERAGE)
TOTAL WITHIN EACH INTERVAL

0.0-0.2	0.3-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0
46800	24300	8100	5400	1800	2700	0	0	0

8.1-9.0	9.1-10
0	0

TOTAL AREA COVERED 89100 SQUARE FEET

> 10
0

PATTERN LENGTH DATA

480 FEET ABOVE	0.0 GALLONS/100 SQUARE FEET
330 FEET ABOVE	.3 GALLONS/100 SQUARE FEET
240 FEET ABOVE	1.0 GALLONS/100 SQUARE FEET
210 FEET ABOVE	2.0 GALLONS/100 SQUARE FEET
120 FEET ABOVE	3.0 GALLONS/100 SQUARE FEET
90 FEET ABOVE	4.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	5.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	6.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	7.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	8.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	9.0 GALLONS/100 SQUARE FEET
0 FEET ABOVE	10.0 GALLONS/100 SQUARE FEET

Figure B4. Summary Data Output (Sample)

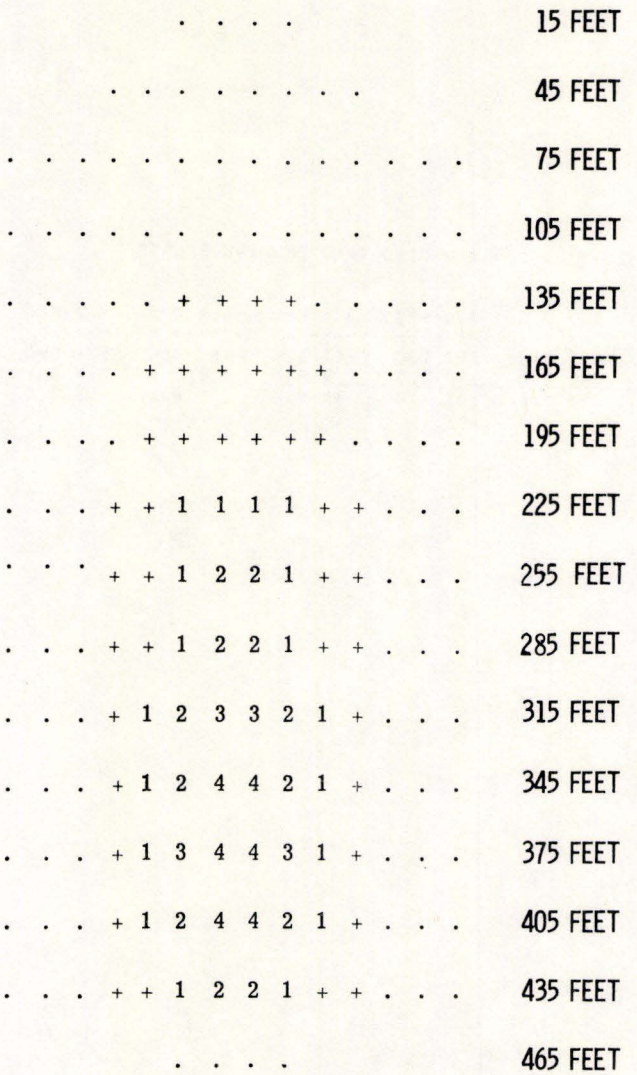

Figure B5. Pattern Data Output in True Scale

MAXIMUM LINE LENGTHS WITH CORRESPONDING TANK OPENING DELAYS

NO. OF	.5 GPC		1.0 GPC		2.0 GPC		3.0 GPC		4.0 GPC		6.0 GPC		8.0 GPC		10.0 GPC	
TANKS	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC	FEET	SEC
1	735	0.0	360	0.0	40	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2	1540	4.4	825	1.9	360	0.0	105	.4	40	0.0	0	0.0	0	0.0	0	0.0

Figure B6. PATADD Output